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THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

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1897.

Parts 1–2.

PUBLISHED BY THE INSTITUTION,
19 Victoria Street, Westminster, S.W.

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PAST-PRESIDENTS.

GEORGE STEPHENSON, 1847–48. (*Deceased* 1848.)

ROBERT STEPHENSON, F.R.S., 1849–53. (*Deceased* 1859.)

SIR WILLIAM FAIRBAIRN, BART., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

JOHN PENN, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

JAMES KENNEDY, 1860. (*Deceased* 1886.)

THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

ROBERT NAPIER, 1863–65. (*Deceased* 1876.)

JOHN RAMSBOTTOM, 1870–71.

SIR WILLIAM SIEMENS, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

SIR FREDERICK J. BRAMWELL, BART., D.C.L., LL.D., F.R.S., 1874–75.

THOMAS HAWKSLEY, F.R.S., 1876–77. (*Deceased* 1893.)

JOHN ROBINSON, 1878–79.

EDWARD A. COWPER, 1880–81. (*Deceased* 1893.)

PERCY G. B. WESTMACOTT, 1882–83.

SIR LOWTHIAN BELL, BART., F.R.S., 1884.

JEREMIAH HEAD, 1885–86.

SIR EDWARD H. CARBUTT, BART., 1887–88.

CHARLES COCHRANE, 1889.

JOSEPH TOMLINSON, 1890–91. (*Deceased* 1894.)

SIR WILLIAM ANDERSON, K.C.B., D.C.L., F.R.S., 1892–93.

ALEXANDER B. W. KENNEDY, LL.D., F.R.S., 1894–95.

The Institution of Mechanical Engineers.

OFFICERS.

1897.

PRESIDENT.

E. Windsor Richards,	Low Moor.

PAST-PRESIDENTS.

Sir William Anderson, K.C.B., D.C.L., F.R.S.,	Woolwich.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Jeremiah Head,	London.
Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
John Ramsbottom,	Alderley Edge.
John Robinson,	Leek.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S.,	London.
Samuel W. Johnson,	Derby.
Francis C. Marshall,	Newcastle-on-Tyne.
Edward P. Martin,	Dowlais.
William H. Maw,	London.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
Henry Davey,	London.
William Dean,	Swindon.
Sir Benjamin A. Dobson,	Bolton.
Bryan Donkin,	London.
John Hopkinson, Jun., D.Sc., F.R.S.,	London.
Arthur Keen,	Birmingham.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Henry D. Marshall,	Gainsborough.
Thomas Mudd,	West Hartlepool.
James Platt,	Gloucester.
John I. Thornycroft, F.R.S.,	London.
A. Tannett Walker,	Leeds.
Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

TREASURER.

Harry Lee Millar.

SECRETARY.

Alfred Bache,

Institution of Mechanical Engineers, 19 *Victoria Street*, *Westminster*, *S.W.*

[Telegraphic address:—*Mech*, *London*. Telephone:—*Westminster*, 264.]

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

FEBRUARY 1893.

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

NOW THEREFORE IT IS HEREBY AGREED as follows:—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s*. additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10*s.*, and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s.* additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being years of age, and desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this day of

Members or Associate Members.

FORM B.

Mr. born on being desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this day of

Members or Associate Members.

FORM C.

If elected an of the Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement and paying the entrance fee and annual subscription in conformity with the By-laws.

Witness my hand, this day of

FORM D.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of of the Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of the Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

Institution of Mechanical Engineers.

PROCEEDINGS.

February 1897.

The Fiftieth Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 4th February 1897, at Half-past Seven o'clock p.m.; E. Windsor Richards, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following fifty candidates were found to be duly elected:—

MEMBERS.

Bird, William Hobart,	Coventry.
Black, James Mark,	Londonderry.
Bradshaw, George Theobald Mathew,	Ballymoney.
Crawford, Walter William,	Sydney.
Dixon, Walter Frank,	Nijni Novgorod.
King, Henry Charles,	Swindon.
Loane, Samuel Joshua,	Madras.
Mantle, Harry George,	Brierley Hill.
McGlashan, William,	Calcutta.
Mendizabal, Carlos,	Bilbao.
Morcom, Alfred,	Birmingham.
Musker, Arthur,	Liverpool.
Musker, Charles,	Liverpool.
Orr, Charles Roger,	Calcutta.

Thomas, Lewis Richard,	Swindon.
Watson, Thomas John,	Newcastle-on-Tyne.
Wills, Frank,	Bridgwater.
Worthington, William Barton,	Manchester.

ASSOCIATE MEMBERS.

Arnold, William,	Birmingham.
Aylesbury, Thomas Antram,	London.
Baker, Tom William,	London.
Bradley, James William,	Wolverhampton.
Burnside, Bertram W.,	Rangoon.
Connell, William Percival,	Huelva.
Crooke, Walter, Jun.,	Doncaster.
Epton, William Martin,	Johannesburg.
Grant, Hector,	Paisley.
Hill, Walter Charles,	London.
Johnson, George,	Johannesburg.
Mansfield, Walter,	Manchester.
Mills, Samuel James Augustus,	Darwen.
Newman, Reginald William,	Penybont, Radnorshire.
Outram, Lieut. Francis Davidson, R.E.,	Aldershot.
Parish, Charles Edward,	Chester-le-Street.
Pickles, John Edward,	Birmingham.
Pilling, Henry,	Manchester.
Scotter, Robert Herbert,	Liverpool.
Shirtliff, Frederick,	Ryde.
Taylor, Arthur Joseph,	Bradford.

ASSOCIATE.

Wallach, Lewis Charles,	London.

GRADUATES.

Donkin, Albert Henry,	London.
Engelbach, Charles Richard Fox,	Newcastle-on-Tyne.
Foster, Sydney,	Fleetwood.
Fox, Beaufoy Howard,	Bhootan, India.
Goulding, Benjamin Joseph John,	London.

Hollingsworth, Allen Alexander,	Sheffield.
Mansfield, Frank,	Manchester.
Maw, Henry,	London.
McGregor, John Leith,	Glasgow.
Slingsby, Walter,	Leeds.

The following Annual Report of the Council was then read :—

ANNUAL REPORT OF THE COUNCIL.

1897.

The Council have the pleasure of presenting to this, the Fiftieth Annual General Meeting of the Members, the following Report of the progress and work of the Institution during the past year.

At the end of last year the number of names in all classes on the roll of the Institution was 2,359, as compared with 2,271 at the end of the previous year, showing a net gain of 88. During 1896 there were added to the register 183 names; against which the loss by decease was 27, and by resignation or removal 68.

During 1896 Baronetcies have been conferred by Her Majesty upon Sir William Coddington, M.P., and Sir Wm. Thomas Lewis, Members of the Institution. As already announced, the Council have had the pleasure of nominating Professor W. Cawthorne Unwin, F.R.S., an Honorary Life Member of the Institution, in appreciation of the eminent position he occupies as a representative of scientific engineering in this country.

The following fifteen Transferences have been made by the Council in 1896:—

To the class of Members.

Anderson, Tom Scott,	Associate Member	Sheffield.
Barker, Eric Gordon,	do.	Birkenhead.
Davidson, Albert,	do.	Sheffield.
Ewen, John Taylor,	do.	Glasgow.
Graham, Maurice,	do.	Birmingham.
Young, Smelter Joseph,	do.	Sheffield.
Cox, Herbert Henry,	Graduate	Falmouth.
Osmond, Frederick John,	do.	Birmingham.

To the class of Associate Members.

McMeekin, Adam,	Associate	Doagh.
Pirrie, John Barbour,	do.	Carrickfergus.
Alperson, George Alexander,	Graduate	Alexandria.

Ashford, John,	Graduate	London.
Buttenshaw, George Eskholme,	do.	Rotherham.
Seymour, William Frederick Earl,	do.	Swindon.
Williams, Arthur Edward,	do.	London.

The following thirty-two Deceases of Members of the Institution have occurred during the past year:—

Abernethy, James, F.R.S.E.,	London.
Adams, William Alexander,	Worcester.
Ashwell, Frank,	Leicester.
Birch, Robert William Peregrine,	London.
Bratt, Augustus Hicks Henery,	Shanghai.
Carter, Frederick Heathcote (Associate),	Manchester.
Chapman, Alfred Crawhall,	Newcastle-on-Tyne.
Clark, Daniel Kinnear,	London.
Cleminson, James,	London.
Gray, John William,	Birmingham.
Greathead, James Henry,	London.
Hayes, John (Associate; deceased 1895),	Birmingham.
Henderson, Thomas,	Liverpool.
Hindson, William,	Gateshead.
Hunt, Thomas,	Stockport.
Johnston, Andrew,	Hong Kong.
Lawson, James Ibbs (Graduate),	Wanganui, N.Z.
Little, George,	Southport.
Martin, Thomas George,	London.
McGregor, Peter,	Hong Kong.
Meik, Thomas,	Edinburgh.
Musgrave, James,	Bolton.
North, John Thomas,	London.
Pearce, Robert McLardy,	London.
Pirrie, John Sinclair,	Melbourne.
Saïd, Marshal M., Pacha,	Constantinople.
Seddon, Robert Barlow (deceased 1895),	Wigan.
Shapton, William,	London.
Stiff, William Charles,	Birmingham.
Tipping, Henry,	London.
Vaizey, John Leonard (Graduate),	Norwich.
Willcox, Francis William,	Sunderland.

Of these Mr. D. K. Clark was a Member of Council in 1863–4.

The following thirty-two gentlemen have ceased to be Members of the Institution during the past year:—

Allen, Samuel Wesley,	Cardiff.
Atkey, Albert Reuben,	Nottingham.
Brown, Robert,	Northampton.
Calastremé, John Carlos (Graduate),	London.
Clift, Leslie Everitt (Graduate),	London.
Coates, Joseph,	London.
Collenette, Ralph,	Bradford.
Durham, Frederick William,	London.
Forbes, Daniel Walker,	London.
Grace, Robert William,	Colorado, U.S.
Hannah, Joseph Edward,	Carlisle.
Hatton, Thomas Reginald (Graduate),	Ross, Herefordshire.
Henderson, William,	Johannesburg.
Human, Edwin (Associate Member),	Colombo.
Hunt, Richard,	London.
Jackson, William (Associate),	Hull.
James, John William Henry,	London.
Lennox, John,	London.
Letchford, Joseph,	Wimbledon.
Lister, Frank,	Keighley.
Locke, Arthur Guy Neville,	Alderney.
Macan, Richard Thompson,	London.
Newall, John Walker (Graduate),	London.
Oswell, William St. John (Graduate),	Buenos Aires.
Perry, Weston Alcock,	Birmingham.
Rochford, John,	Dublin.
Rock, John William,	Sydney.
Sanders, Percy Henry (Graduate),	London.
Sellier, Alphonse Louis,	Trinidad.
Silcock, Charles Whitbread (Graduate),	Surbiton.
Thornton, Robert Samuel,	Etawah, India.
Watt, Charles,	Melbourne.

In addition to these there have been thirty-six Resignations of membership.

The Accounts for the year ending 31 December 1896 are now submitted to the Members (*see* pages 12–15), after having been passed by the Finance Committee, and certified by Mr. Robert A.

McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £7,388 15*s.* 9*d.*, while the expenditure, actual and estimated, was £5,215 8*s.* 1*d.*, leaving a balance of receipts over expenditure of £2,173 7*s.* 8*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £46,061 17*s.* 2*d.*; and allowing £600 for accounts owing but not yet rendered, the capital of the Institution amounts to £45,461 17*s.* 2*d.*, of which £24,028, as seen from the balance sheet, still remains mostly invested in Railway Debenture Stocks, registered in the name of the Institution, while £16,877 5*s.* 4*d.* has already been expended on account of the Institution House. The certificates of the whole of the securities have been duly audited by the Finance Committee and the auditor.

During the past year the preparatory work for the Institution House on the site acquired at Storey's Gate, Westminster, has been gone on with, to the extent of completing the foundations and substructure; and as soon as the preliminaries still pending with the Office of Works and the County Council have been settled, the erection of the superstructure will be at once proceeded with.

Pending the realisation of results from the laboratory experiments in progress at University College, London, for the Research Committee on the Value of the Steam-Jacket, of which Mr. Henry Davey is the chairman, a report was read and discussed at the last meeting upon the trial made, through the kindness of Mr. Aspinall, with a steam-jacketed locomotive on the Lancashire and Yorkshire Railway.

The Alloys Research Committee, under the chairmanship of Sir William Anderson, have received from Professor Roberts-Austen his Fourth Report, dealing with many important features of alloys in general, and with Brasses in particular. This Report is announced for reading and discussion at the present meeting.

The Research Committee respecting the temperatures and pressures and other conditions pertaining to the working of Gas

Engines, of which Professor Kennedy is the chairman, have been occupied with the preparation and arrangement of the necessary apparatus for the investigation of this subject, and with preliminary experiments for ascertaining the best mode of procedure for the accomplishment of the object in view.

An additional Research Committee for investigating questions connected with the working of Steam Engines has been appointed during last year, under the chairmanship of Mr. Bryan Donkin; and an engine suitable for experiments of the kind contemplated is in preparation.

The Library of the Institution has received by presentation and exchange during the past year the additions enumerated in pages 18–25, for which the Council here record their thanks to the several donors. Members who have published works valuable for reference, or original pamphlets on engineering subjects, or records of experiments, of which they could present copies, are reminded that such contributions to the Library are acceptable for permanent preservation.

The General Meetings in 1896 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting in Belfast; and the Autumn Meeting in London. Altogether eight sittings were occupied in the reading and discussion of the following fourteen Papers, which are published in the Proceedings:—

Telemeters and Range-Finders for naval and other purposes; by Professors Barr and Stroud.

Calculation of Horse-Power for Marine Propulsion; by Lt.-Colonel Thomas English.

Address by the President, E. Windsor Richards, Esq.

Notes on Steam Superheating; by Mr. William H. Patchell.

Steel Steam-Pipes and Fittings, and Benardos Arc Welding in connection therewith; by Mr. Samuel MacCarthy.

Flax Scutching and Flax Hackling Machinery; by Mr. John Horner.

Electric Lighting in Belfast; by Mr. Victor A. H. McCowen.

Unusual Corrosion of Marine Machinery; by Mr. Hector MacColl.

Notes on the Introduction and Development of Rope Driving; by Mr. Abram Combe.

Description of the Alumina Factory at Larne Harbour; by Mr. James Sutherland.

Description of the Belfast Gas Works; by Mr. James Stelfox.

Research Committee on the Value of the Steam-Jacket; Experiment on a Locomotive Engine. By Professor T. Hudson Beare, F.R.S.E., and Mr. Bryan Donkin.

Transmission of Heat from Surface Condensation through Metal Cylinders; by Lt.-Colonel Thomas English and Mr. Bryan Donkin.

Breakdowns of Stationary Steam-Engines; by Mr. Michael Longridge.

The attendances during 1896 were as follows:—at the Annual General Meeting 108 Members and 93 Visitors; at the Spring Meeting 81 Members and 91 Visitors; at the Summer Meeting 213 Members and 88 Visitors; and at the Autumn Meeting 86 Members and 62 Visitors.

Of the Summer Meeting in the city of Belfast a fore-taste had been enjoyed by many of the Members eight years previously, in a day's visit made there from Dublin in 1888. The cordiality of their former welcome was on this occasion renewed with equal warmth and hospitality by the Right Honourable the Lord Mayor, himself a Member of the Institution, and by the Reception Committee composed of the local Members and their friends. The old staple industries of the neighbourhood were dealt with in papers on flax scutching and flax hackling machinery, and on the introduction and development of rope-driving, which here took its origin forty years ago. Municipal engineering was represented by descriptions of the gas works, the electric lighting station, and the main drainage works; and marine engineering by the record of an instance of unusual corrosion in marine machinery, and by visits to the shipbuilding and engineering establishments which have contributed so largely to the prosperity and renown of Belfast. The extent and importance of the harbour works were appreciated in a visit of inspection, made by invitation of the Harbour Commissioners, and aided by a description of the engineering features and growth of the port. Some idea of the extending employment of aluminium for engineering and manufacturing purposes was derived from a description of the alumina factory at Larne Harbour, and from an excursion made thither to witness the preparatory processes for the production of the metal. For visits to the principal flax mills and engineering and manufacturing establishments in Belfast, special facilities were provided by the kindness of the Reception Committee, under the chairmanship of Mr. Walter H. Wilson. On the invitation of the President of Queen's College, the reading of the papers took place in the large hall of that fine building. By the hospitality of the Right Honourable the Lord Mayor, Alderman W. J. Pirrie, and the Lady Mayoress, the Members were entertained at a Conversazione in the Free Library and Art Galleries. For the concluding day, excursions were arranged by the kindness of the Reception Committee and of the three Railways serving Belfast.

To the three gentlemen who so obligingly undertook jointly the duties of Honorary Secretary—Mr. Bowman Malcolm, Mr. A. Basil Wilson, and Mr. Robert Meyer—the Council have expressed on behalf of the Members their grateful sense of indebtedness, by presenting to each a silver salver with suitable inscription, in appreciation of their active exertions for maturing the necessary arrangements and for promoting the enjoyment of all who attended the Belfast Meeting.

As the present year is the jubilee of the establishment of the Institution in 1847, the Council purpose commemorating the event by holding the Summer Meeting in its birthplace, the city of Birmingham.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of the Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.

ACCOUNTS AND BALANCE SHEET.

1896.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1896	943	12	1			
Less Authors' Copies of Papers, repaid	12	15	0	930	17	1
„ Stationery and General Printing				192	5	11
„ Binding				26	7	1
„ Rent of Offices				710	0	0
„ Salaries and Wages				1,892	3	0
„ Coal, Firewood, and Lighting				47	18	1
„ Fittings and Repairs				13	0	4
„ Postages, Telegrams, and Telephone				254	15	1
„ Insurance				7	0	6
„ Petty Expenses				54	17	11
„ Meeting Expenses—						
Printing	166	2	4			
Reporting	53	4	8			
Diagrams, Screen, &c.	228	1	2			
Travelling and Incidental Expenses	243	19	5	691	7	7
„ Dinner Guests				78	7	8
„ Research				307	8	3
„ Books purchased				8	19	7
				5,215	8	1
Accounts owing, not yet rendered, say	600	0	0			
Less Reserve in previous year for accounts since paid	600	0	0	0	0	0
Balance, being excess of Receipts over Expenditure, carried down—				2,173	7	8
				£7,388	15	9

	£	s.	d.	£	s.	d.
To House for Institution—						
Expended this year on Building, Land Lease, and Freehold Land	14,251	8	9			
Ground Rent during construction	850	8	2	15,101	16	11
Cash Balance 31st December 1896				3,193	11	10
				£18,295	8	9

FOR THE YEAR ENDING 31st DECEMBER 1896. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
67 *New Members at £2*	134	0	0			
80 *New Associate Members at £1*	80	0	0			
10 *New Associates at £1*	10	0	0			
6 *Associate Members transferred to Members at £1*	6	0	0			
2 *Graduates transferred to Members at £1*	2	0	0	232	0	0
„ Subscriptions for 1896—						
1645 *Members at £3*	4,935	0	0			
202 *Associate Members at £2 10s.*	505	0	0			
1 *Associate Member, balance*	1	0	0			
66 *Associates at £2 10s.*	165	0	0			
156 *Graduates at £1 10s.*	234	0	0			
6 *Associate Members transferred to Members at 10s.*	3	0	0			
2 *Graduates transferred to Members at £1 10s.*	3	0	0			
5 *Graduates transferred to Associate Members at £1*	5	0	0	5,851	0	0
„ Subscriptions in arrear—						
93 *Members at £3*	279	0	0			
4 *Associate Members at £2 10s.*	10	0	0			
9 *Associates at £2 10s.*	22	10	0			
1 *Graduate at £2*	2	0	0			
18 *Graduates at £1 10s.*	27	0	0	340	10	0
„ Subscriptions in advance—						
21 *Members at £3*	63	0	0			
5 *Associate Members at £2 10s.*	12	10	0	75	10	0
„ Interest—						
From Investments	818	13	10			
From Bank	22	18	5	841	12	3
„ Reports of Proceedings—						
Extra Copies sold				48	3	6
				£7,388	15	9

	£	s.	d.
By Balance brought down	2,173	7	8
By Life Compositions	165	0	0
By Balance from conversion of N. E. Ry. Debenture Stock	0	8	0
By Sale of Investments	13,333	13	0
Cash Balance 31st December 1895	2,623	0	1
	£18,295	8	9

Dr.

BALANCE SHEET

	£	s.	d.
To Sundry Creditors—			
Accounts owing, not yet rendered, say	600	0	0
Capital of the Institution at this date . . . . (exclusive of back numbers of Proceedings, which cost £5,100)	45,461	17	2
	£46,061	17	2

Signed by the following members of the Finance Committee:—

E. WINDSOR RICHARDS,	WILLIAM H. MAW,
ALEXANDER B. W. KENNEDY,	BRYAN DONKIN,
DOUGLAS GALTON,	JOHN HOPKINSON.

AS AT 31st DECEMBER 1896. *Cr.*

	£	s.	d.	£	s.	d.	£	s.	d.
By Cash—*In Union Bank, on Deposit*				2,200	0	0			
„ „ „ *on Current account* . .				493	11	10			
In London Joint Stock Bank	353	14	11						
In hand { *expended since closing accounts* }	146	5	1	500	0	0	3,193	11	10
„ Investments—(*cost* £18,101 14*s.* 6*d.*)									
£									
2,244 *Great Eastern Railway* 4% *Debenture Stock*									
2,755 *Metropolitan* „ „ „ „									
2,325 „ „ 3½% „ „									
4,237 *London and North Western Ry.* 3% „ „									
3,288 *Midland Railway* „ „ „									
4,053 *India* 3% *Stock*									
The Market Value of these investments at 31st Dec. 1896 was about . .							24,028	0	0
„ Subscriptions in Arrear, probable value							280	0	0
„ Office Furniture and Fittings							343	0	0
„ Library							1,240	0	0
„ Drawings, Engravings, Models, Specimens, and Sculpture .							100	0	0
„ Proceedings, back numbers, cost £5,100									
„ House for Institution, expenditure to date							16.877	5	4
							£46,061	17	2

Audited and Certified by

ROBERT A. McLEAN, F.C.A.,
Auditor,
1 Queen Victoria Street, London, E.C.

WILLANS PREMIUM FUND.

		£	s.	d.
Investment £159 8*s.* 5*d.* of India 3% Stock	cost	165	5	0
Amount held in trust by Institution of Mechanical Engineers—				
Interest received during 1895		2	7	8
„ „ „ 1896		4	15	4
Audited, certified, and signed by the names on pages 14–15.		£7	3	0

DECLARATION OF TRUST

OF THE WILLANS PREMIUM FUND.

To all to whom these presents shall come The Institution of Mechanical Engineers and The Institution of Electrical Engineers send greeting. Whereas a Fund has been subscribed by the friends of the late Peter William Willans, of Thames Ditton, for the purpose of commemorating his name and the services which he rendered to Engineering and Electrical science; and at the request of the subscribers to the said fund the above-named Institutions have agreed to act as joint Trustees thereof, and the sum of One hundred and sixty-five pounds has accordingly been paid to the said Institutions: now these presents witness that the said Institutions do hereby declare the Trusts upon which they hold the said fund to be as follows:—

1. To invest the said fund upon such securities as trustees are by law authorised to hold, and in such names as the Councils of the two Institutions shall from time to time direct.

2. To apply the proceeds of the said investment as and when received, after payment of any expenses incidental to the administration of the trust, to the Premium hereinafter described, to be known as "the Willans Premium."

3. The Willans Premium shall be awarded alternately by the Council of each of the above-mentioned Institutions; and first by the Institution of Electrical Engineers in December 1897.

4. The Council of the awarding Institution in each alternate period shall award the Willans Premium for the best original paper communicated to their Institution, dealing with such a general subject as the utilisation or transformation of energy, treated especially from the point of view of efficiency or economy: provided that the Premium shall not be awarded unless a paper of sufficient merit in the judgment of the awarding Council shall have been so communicated since the preceding award of that Council.

5. The Premium shall be awarded triennially in and after December 1897, unless otherwise determined by resolution of the respective Councils of the two Institutions.

6. The Premium may be awarded either in money or books or medal, or in any other form which in the instance of any individual award the awarding Council may then determine.

7. In case of no award at the end of any triennial period, the premium available for that award shall be added to the capital of the fund.

In witness whereof the Institution of Mechanical Engineers have hereunto affixed their common seal, and the President and Secretary of the Institution of Electrical Engineers have hereunto set their hands, this sixteenth day of January 1895.

The Seal of the Institution of Mechanical Engineers was impressed by the President in the presence of Alfred Bache, Secretary; and the document was signed as follows:—

Alexander B. W. Kennedy,
President of the Institution of Mechanical Engineers.
R. E. Crompton,
President of the Institution of Electrical Engineers.
F. H. Webb, Secretary of the Institution of Electrical Engineers.

LIST OF DONATIONS TO LIBRARY.

The Cotton Trade in England and on the Continent, by Dr. G. von Schulze-Gaevernitz, translated by Oscar S. Hall; from the translator.

Sewerage and Sewage Disposal, by Professor Henry Robinson; from the author.

Tabulated Weights of Angle, Tee, and Bulb Iron and Steel, by C. H. Jordan; from the author.

Griffin's Electrical Engineer's price-book (second edition); from the publishers.

Original Drawing, 1847, of Stephenson long-boiler Locomotive built at Railway Foundry, Leeds; from Mr. David Joy.

The Cambridge of eighteen hundred and ninety-six; from Mr. E. D. Leavitt, Jun.

Gas, Oil, and Air Engines, by Bryan Donkin (second edition, 1896); from the author.

Machine Drawing, by T. Jones and T. G. Jones; from Mr. T. Jones.

Graphical Calculus, by A. H. Barker; from the author.

Spectator Mathematical Tables (Actuarial), by J. W. Gordon; from the editor, Insurance Spectator of London.

Practical Treatise on the Otto Cycle Gas Engine, by W. Norris; from the author.

Practical Plane and Solid Geometry, including Graphic Arithmetic, by H. J. Spooner; from the author.

Steam Navigation to India; from Mr. Richard Watkins.

Transformers for single and multiphase currents, by Gisbert Kapp; from Messrs. Whittaker and Co.

Auto-Cars, by D. Farman; from Messrs. Whittaker and Co.

Carriages without Horses shall go, by A. R. Sennett (two copies); from the author and Messrs. Whittaker and Co.

Atlas des Voies Navigables de la France—Navigation de la Seine, Traversée de Paris; from the Ministère des Travaux publics.

Commercial Organisation of Factories, by J. Slater Lewis; from Messrs. E. and F. N. Spon.

The Pontine Marshes, by F. M. von Donat; from Herr Karl von Donat.

Distribution de Vapeur à tiroirs d'admission et d'échappement indépendants, by E. Polonceau; from Mr. Henry Chapman.

Chairman's Address, Nottingham section, Society of Chemical Industry, 1895; from Mr. F. J. R. Carulla.

Carbides of Iron, by F. L. Garrison ; from the author.

Production of Chromium and Tungsten in 1894, by F. L. Garrison; from the author.

Holloway-Longridge process for extracting Gold from Auriferous Antimony Ores, by Captain C. C. Longridge ; from the author.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 Dec. 1895 and 30 June 1896 ; from the Registrar.

Kitchen Boiler Explosions; from Mr. Lavington E. Fletcher.

Water Supply to Mansions, Villages, &c. ; from Messrs. Merryweather and Sons.

Photographs (two) of Compound Locomotives built at the Railway Works, Kobe, Japan ; from Mr. R. F. Trevithick.

Traction Mécanique des Tramways, by L. Francq ; from the author.

Traction Mécanique des Tramways: Moteurs à vapeur sans feu ou à eau chaude, by L. Francq ; from the author.

Report of Committee on the Manufacture of Compressed-Gas Cylinders ; from Professor W. Cawthorne Unwin.

Industrial Explorings in and around London, by R. Andom ; from the author.

Indicator Diagrams and Engine and Boiler Testing, by Charles Day ; from the author.

The following from the Ordnance Office, Washington, U.S. America :—Annual Report of the United States Chief of Ordnance, 1895 ; Tests of Metals, &c., at Watertown Arsenal, Massachusetts, 1894 ; Notes on the Construction of Ordnance.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1896 ; from the Inspector-General of Chinese Customs.

Vergleichende Versuche mit gesättigtem und mit überhitztem Dampf, by M. Schröter ; Untersuchung einer Heiss-dampf-maschinen-anlage (System Schmidt), by M. Schröter ; from the author.

Ferro-Carril Andino, Seccion de San Luis á la Paz y Mendoza ; from Mr. F. J. R. Carulla.

Sheffield Smoke-Abatement Association : Report as to the Stoking Competition held March 1896, by R. Heber Radford ; from the author.

Report of the Hydraulic Engineer on the Water Supply of Queensland, 1895 ; from Mr. John B. Henderson.

Brief notes upon Artesian Wells and Boring for Artesian Water in Queensland, by John B. Henderson ; from the author.

Carburo di Calcio e la preparazione industriale del Gas Acetilene, by A. Pacchioni ; from the author.

L'Apprentissage dans les ateliers des Chemins de fer Français, by E. Sauvage ; from the author.

Report of the Kew Observatory Committee, 1895 ; from the Committee.

Étude historique sur les Armes à tir automatique; from the publishers.

Report of the Inspection of Mines in India, 1894 and 1895, by James Grundy; Indian Public Works Department, serial No. 30; from the India Office.

Speed control in modern Steamers, by Lieut. M. L. Wood, U.S.N.; from the United States Naval Institute.

Sanitary Institute, illustrated list of Exhibits, 1896; from the Institute.

Report relating to the Public Works Department of the Johannesburg Gezondheids Comite, 1895, by Charles Aburrow; from the author.

Report on proposed Water Supply to Coolgardie Goldfields (by pumping), from reservoirs in the Greenmount Ranges, by C. Y. O'Connor; from the author.

Model of a Horizontal Steam-Engine, by C. Volkert; Systematic course of Geometrical Drawing, by T. A. V. Ford; from the publishers.

Original Bradshaw's Railway Companion, 1843; from Mr. Middleton Pratt.

Circulation in Water-Tube Boilers, by Professor W. H. Watkinson; from the author.

Brunner Coal-Mine Disaster, Report of Royal Commission appointed 26 March 1896; from Sir James Hector, K.C.M.G.

Patents for inventions relating to Machine-Guns and Automatic Breech-Mechanism, by W. R. Lake; from the author.

Power Locomotion on the Highway, by Rhys Jenkins; from the author.

The Light Railways Act, 1896, by Evans Austin; from the author.

Railway Rates and Terminal Charges, by R. Price-Williams; from the author.

Modern Economy in Steam Engines, by William Arnold; from the author.

Annual Report of the Chief of the Bureau of Steam Engineering, United States Navy Department; from the Bureau.

Institute of Secretaries, Proceedings &c. 1896; from the Institute.

The following official publications from the Government of New South Wales: —Annual Report of the Railway Commissioners for the year ending 30 June 1895; Eleventh General Report of Committee on Public Works, 1896; Report on a proposed system of Rapid Transit for the City of Sydney and Suburbs; Statistical Register, 1894 and previous years, by T. A. Coghlan; Wealth and Progress of New South Wales, 1894 (two vols.), by T. A. Coghlan; New South Wales, the Mother Colony of the Australias, 1896.

Address to the Engineering School of University College, Bristol, by J. Wolfe Barry, C.B.; from the author.

Bericht über die Königliche Technische Hoch-schule zu München, 1895–6; from the School.

Report on the working of the Boiler Explosions Acts 1882 and 1890, during the year ending 30 June 1896; Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Economic Combustion of Fuel, by Frederick Grover; from the author.

Navigation Canals in India, by J. H. Apjohn; Steam Launch Construction, by W. E. Steele; Railway Management in Bengal, by S. Finney; Railway Construction in Bengal, by S. Finney; from Sibpur Civil Engineering College.

Life and Work of Hirn; and the experimental theory of the Steam Engine, by Professor W. Cawthorne Unwin; from the author.

Lockwood's Builder's and Contractor's price-book, 1896; from the publishers.

Spons' Engineers' and Contractors' Diary and Year-book, 1897; from the publishers.

Wire Mining and Hauling Ropes, their manufacture and applications, by J. B. Smith; from Messrs. Bullivant and Co.

Gas Engineer's Pocket Almanack, 1897; from Messrs. W. Sugg and Co.

Le Guide-adresses Français, 1894; from Mr. Henry Chapman.

Aluminium; from the Aluminium Supply Co.

Universal Directory of Railway Officials, 1896, by S. R. Blundstone; from the Directory Publishing Co.

Mining at Great Depths, by Bennett H. Brough; from the author.

Calendars 1896–7 from the following Colleges:—Royal Technical High School, Berlin; Mason Science College, Birmingham; Municipal Technical School, Brighton; University College, Bristol; Glasgow and West of Scotland Technical College; Yorkshire College, Leeds; Battersea Polytechnic Institute, London; City of London College; Royal Technical High School, Munich; Firth College, Sheffield.

Yorkshire College, Leeds, Annual Reports, 1894–5 and 1895–6; from the College.

University College, Bristol, Annual Report, 1894–5; from the College.

Central Technical College, City and Guilds of London Institute, Programme January 1896; from the College.

Civil Engineering College, Sibpur, Calendar 1896; from the College.

Illustrated catalogue of Railway Plant &c.; from Messrs. A. Barclay, Sons and Co.

Illustrated catalogue of Electric-Light Fittings &c.; from Messrs. H. M. Salmony and Co.

Illustrated catalogue of Electrical Apparatus; from Messrs. Dorman and Smith.

Illustrated catalogue of Sirocco Tea Machinery &c.; from Messrs. Davidson and Co.

Illustrated price-list of Wrought-Iron Pulleys, Shafting, and Friction Couplings; from Messrs. J. Bagshaw and Sons.

From the United States Geological Survey.

Fifteenth and Sixteenth (Parts 2, 3 and 4) Annual Reports of the United States Geological Survey, 1893-4 and 1894-5, by J. W. Powell.

Bulletins of the United States Geological Survey, Nos. 123-126, 128, 129, and 131-134.

From the Patent Office.

The following Abridgments of Specifications of Patents for Inventions, 1884-88:—Classes 1-9, 11, 13-17, 19, 21-33, 35-37, 39-43, 45-50, 53-59, 62, 63, 65, 67, 70-74, 76, 77, 79, 82, 84, 86, 88, 90-92, 96-101, 103-105, 109, 111-117, 119-122, 124, 127, 129, 131, 132, 134, 136, 139, 141-146.

The following Publications from the respective Societies and Authorities:—

Reports of the Academy of Science, France.
Engravings from the École des Ponts et Chaussées, Paris.
Annales des Ponts et Chaussées, Paris.
Proceedings of the French Institution of Civil Engineers.
Journal of the French Society for the Encouragement of National Industry.
Annales des Mines.
Annales du Conservatoire des Arts et Métiers.
Journal of the Marseilles Scientific and Industrial Society.
Bulletins of the French Technical Maritime Association.
Proceedings of the Industrial Society of St. Quentin et de l'Aisne.
Proceedings of the Industrial Society of the North of France.
Proceedings of the Industrial Society of Rouen.
Proceedings of the Industrial Society of Mulhouse.
Annals of the Association of Engineers of Ghent.
Proceedings of the Society of German Engineers.
Reports of the Royal Academy of Science, Belgium.
Reports of the Royal Institute of Engineers, Holland.
Bulletins of the Commission Internationale du Congrès des Chemins de fer.
Proceedings of the Engineers' and Architects' Society of Canton Vaud.
Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Engineers' and Architects' Society of Prague.
Proceedings of the Architects' and Engineers' Society of Hannover.
Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Engineers' and Architects' Society of Milan.
Proceedings of the Swedish Technical Society.

Journal of the Norwegian Technical Society.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
United States Patent Office Gazette.
Journal of the Association of Engineering Societies.
Journal of the United States Artillery.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Committee of Locomotive and Carriage Superintendents for India.
Journal and Proceedings of the Royal Society of New South Wales.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Philosophical Transactions and|Proceedings of the Royal Society of London.
Proceedings of the Royal Society of Edinburgh.
Proceedings of the Royal Institution of Great Britain.
Transactions and Professional Notes of the Surveyors' Institution.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Journal of the Royal Agricultural Society of England.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Journal of the Royal Institute of British Architects.

Transactions of the Incorporated Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.
Transactions of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions and Proceedings of the Royal Irish Academy.
Transactions of the Institution of Civil Engineers of Ireland.
Transactions of the Institute of Marine Engineers.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Transactions of the Manchester Association of Engineers.
Transactions of the Institution of Junior Engineers.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.
Report to the Council of the Neapolitan Steam Boiler Association, by Francesco Sinigaglia; from the Association.
Forty-third Annual Report of the Liverpool Free Public Library.
Forty-fourth Annual Report of the Manchester Public Free Libraries.
Fifteenth Annual Report of the Newcastle-on-Tyne Public Libraries.
Catalogue of Additions during 1895 to the Radcliffe Library, Oxford.

The following Periodicals from the respective Editors :—

Arms and Explosives.
The Builder.
Camera Club Journal.
Cassier's Magazine.
Der Civil-Ingenieur.
The Colliery Guardian.
The Contract Journal.
Daily Tenders and Contracts.
The Electrical Engineer (from Mr. John T. Ewen).
The Electrical Review.
The Engineer.
Engineering.
The Engineering and Mining Journal.
The Fireman.
The Journal of Gas Lighting.
Giornale del Genio Civile.
Glaser's Annalen.
Hardware Trade Journal.
The Indian and Eastern Engineer.
L'Industrie.
Industries and Iron.
The Iron and Coal Trades Review.
Iron Trade Circular, Ryland's.
The Ironmonger.
Ironmongery.

Lightning.
London Technical Education Gazette.
The Machinery Market.
The Marine Engineer.
The Mariner.
The Mechanical World.
The Mining Journal.
Phillips' Monthly Machinery Register.
The Plumber and Decorator.
The Practical Engineer.
The Printer's Engineer.
The Railway Engineer.
Railway Master Mechanic.
The Railway Review.
Revue générale des Chemins de fer.
Revue industrielle.
Revue universelle des Mines.
The Shipping World.
Stahl und Eisen.
The Steamship.
The Textile Recorder.
Transport.

The President had great pleasure in moving the adoption of the Annual Report of the Council, and inviting discussion thereon.

The members would, he was sure, be pleased to know that, in addition to the gentlemen mentioned in the Report as having received distinctions, their Past-President, Dr. William Anderson, C.B., had been promoted to the rank of Knight Commander of the Bath; and Mr. James Musgrave, Chairman of the Belfast Harbour Commissioners, who had so kindly and hospitably entertained the members on the occasion of their visit to the Harbour Works during the recent Belfast meeting, had received the honour of a Baronetcy. Votes of congratulation had been passed to both these gentlemen at the Council meeting held today.

In regard to the Institution House, he was glad to be able to report that the requirements of the Office of Works and the County Council had been so far met that the erection of the building was now being proceeded with, and it was expected to be completed in about eighteen months. For inspection by the members, plans were exhibited of the building, showing the meeting room, 59 feet long by 39 feet wide, the reading and smoking room looking out upon St. James's Park, the library, and the tea room.

(The President.)

As this was the Jubilee Year of the Institution, which had been formed fifty years ago in Birmingham, the Summer Meeting would be held in the city of its birth. Preparations were in progress for marking the meeting as an auspicious occasion; and as soon as the arrangements were somewhat matured the members would be duly informed of the outline programme.

From the accounts and balance sheet it would be seen that the Institution was financially in a prosperous condition. The excess of receipts over expenditure, exclusive of payments on account of the new building, had amounted last year to £2,100; and the capital of the Institution was estimated at over £45,000. In 1895 it had been £42,000, and in 1894 over £38,000. These figures he thought indicated good progress.

With respect to the Research Committee, it was now generally admitted that everything must be done to bring scientific research into line with the practical application of knowledge to industry and commerce. In the immediate future, steps would doubtless be taken for perfecting the system of technical education throughout the country; and apart from this, for which the need was so obvious, facilities for research would, it was certain, be greatly extended. The magnificent gift to the nation by Dr. Ludwig Mond, F.R.S., who had established and endowed the Davy-Faraday Research Laboratory at the Royal Institution in London, and the bequest by the late Mr. Alfred Nobel of a large sum to be devoted to prizes for discoveries in physics and other sciences, were only indications of the wide-spread demand for scientific investigation. This demand had found expression in letters published in the *Times* during the months of August and September last, many of which had been accompanied by appeals to follow the example of Germany, where research had so long been encouraged both by the state and by private manufacturers. It was satisfactory to remember that the Institution of Mechanical Engineers had never lost sight of the importance of scientific research, as was abundantly testified by the results of the labours of its various committees. Other societies, it was true, contributed to the cost of the work of individual investigators: for instance, the Royal Society administered a government grant of £4,000, which was spread over the sciences generally, and the Chemical Society gave grants to individual chemists; but the Institution of Mechanical Engineers not only appointed committees, and entrusted them with the investigation of specific subjects of scientific and technical interest, but defrayed the cost and directed the course of the experiments. It was gratifying to be told in the Fourth Report of Professor Roberts-Austen to the Alloys Research Committee, now about to be read and discussed, that the value of the experiments on the nature and properties of alloys, which had been originated by the Institution of Mechanical Engineers in 1890, had received wide and appreciative recognition both in this country and abroad. In the demand for more time and money to be devoted by the nation to research, it should not be forgotten how much good work of the kind advocated had already been long accomplished by members of this Institution; and the Council, whilst fully alive to the necessity of economy at the present time, had voted a further sum of £250 to the Alloys Research Committee for extended investigations. Their action in this matter he was sure would meet with the warm approval of the members.

He now moved that the Annual Report of the Council with the statement of accounts be received and adopted.

The motion was unanimously agreed to.

The President announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected:—

PRESIDENT.

E. Windsor Richards,	Low Moor.

VICE-PRESIDENTS.

Edward P. Martin,	Dowlais.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

Benjamin A. Dobson,	Bolton.
Henry D. Marshall,	Gainsborough.
James Platt,	Gloucester.
John I. Thornycroft, F.R.S.,	London.
Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

The Council for the present year will therefore be as follows:—

PRESIDENT.

E. Windsor Richards,	Low Moor.

PAST-PRESIDENTS.

Sir William Anderson, K.C.B., D.C.L., F.R.S.,	Woolwich.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Jeremiah Head,	London.
Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
John Ramsbottom,	Alderley Edge.
John Robinson,	Leek.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir Dougls Galton, K.C.B., D.C.L., LL.D., F.R.S.,	London.
Samuel W. Jcinson,	Derby.
Francis C. Mashall,	Newcastle-on-Tyne.
Edward P. Matin,	Dowlais.
William H. Mw,	London.
J. Hartley Wiksteed,	Leeds.

MEMBERS OF COUNCIL.

John A. F. Asinall,	Horwich.
Henry Davey,	London.

William Dean,	Swindon.
Benjamin A. Dobson,	Bolton.
Bryan Donkin,	London.
Dr. John Hopkinson, F.R.S.,	London.
Arthur Keen,	Birmingham.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Henry D. Marshall,	Gainsborough.
Thomas Mudd,	West Hartlepool.
James Platt,	Gloucester.
John I. Thornycroft, F.R.S.,	London.
A. Tannett Walker,	Leeds.
Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

The President cordially thanked the members for re-electing him to the honourable position of occupying the chair for the present year. He could assure them that he would devote his best energies, and give his utmost attention to the interests of the Institution. By the present election he was sorry to find that the Council had lost for a time a highly valuable colleague in Mr. T. Hurry Riches. Of course the fortune of the ballot could not be gainsaid, and it resulted in the advantage of new names being year by year brought into the Council; but he was sure he was only expressing the views of his colleagues when he said that the services of their tried friend, Mr. Riches, would be greatly missed.

The President reminded the Members that at the present meeting the appointment had to be made of an Auditor for the current year.

On the motion of Mr. Frederick Edwards, seconded by Mr. G. W. Hawksley, it was unanimously resolved that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the current year at the same remuneration as at present, namely Twenty-five Guineas.

The following Paper was then read and partly discussed:—

"Fourth Report to the Alloys Research Committee." By Professor W. C. ROBERTS-AUSTEN, C.B., F.R.S.

At Ten o'clock the Meeting was adjourned till the following evening. The attendance was 88 Members and 78 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Friday, 5th February 1897, at Half-past Seven o'clock p.m.; E. WINDSOR RICHARDS, Esq., President, in the chair.

The Discussion was resumed upon Professor Roberts-Austen's Fourth Report to the Alloys Research Committee; and the following Paper was read and discussed:—

"Partially immersed Screw-Propellers for Canal Boats; and the influence of Section of Waterway." By Mr. HENRY BARCROFT, of Newry.

The remaining Paper announced for reading and discussion was adjourned to the following Meeting.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in allowing the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at a Quarter before Ten o'clock. The attendance was 75 Members and 77 Visitors.

FOURTH REPORT TO THE ALLOYS RESEARCH COMMITTEE.

By Professor W. C. ROBERTS-AUSTEN, C.B., F.R.S.

Introduction.—In presenting this Fourth Report * to the Alloys Research Committee, I would observe that it will deal—first, with some general considerations respecting the present position of the Research; second, with the Copper-Zinc series of alloys, known as the Brasses, which possess much industrial importance; and third, with certain relations between the fusibility and strength of Alloys, which involve considerations as to the constitution of alloys generally. An account will also be given of an experimental investigation, which was undertaken with a view to measure the molecular mobility of solid and molten metals, known as "diffusion." Certain experiments will also be described, the results of which have improved the recording pyrometer, and have rendered its calibration more accurate by direct comparison with the air thermometer.

General Observations.—Before reference is made to the work which has been done recently, some general observations may be offered which might escape attention if they were included in the description of the later investigations.

The value of the experiments on the nature and properties of alloys, which were originated by the Institution of Mechanical Engineers in 1890, has received wide and appreciative recognition in this country and abroad. It may fairly be claimed that they have stimulated similar work in France in a remarkable way; for the constitution of our Alloys Research Committee, and the course they have adopted, have been closely followed in the arrangements of the "Commission des Alliages" of the Société d'Encouragement. The names of some of the best known scientific workers in France are included in the list of this Commission; and what is justly called a "vast programme of research" has been entrusted to six experimenters whose individual reputations are already well established. The Institution of Mechanical Engineers has conducted the researches on alloys entirely at its own cost; but in France the "necessary resources for the realisation of the experiments" have been furnished in part by the Société d'Encouragement, and in part by individuals and public companies. The list of these includes M. Solvay, la Société Royale Asturienne, six of the great railway companies of France, la Société des Forges et Aciéries de la Marine, la Société de Chatillon et Commentry, and la Société Française des Métaux. The first report of this Commission has been published during the present year, and reference will subsequently be made to it. The Institution of Mechanical Engineers however has not only influenced indirectly the advance of scientific knowledge by stimulating research in other countries; it has done much to sustain the reputation of our own country, by affording means for conducting experiments, the results of which have a scientific as well as an industrial application. The necessity for keeping pace with such research work as is being done in Germany has been strenuously urged in letters published in "The Times" during the months of August and September last; and it does not seem to be recognised how much good work, of the kind advocated, has already been accomplished by this Institution. It should not be forgotten moreover that excellent investigations on alloys have also recently been made at Cambridge by Heycock and Neville, whose work has been carried on side by side with that of our Committee.

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* For First, Second, and Third Reports,
see Proceedings 1891, page 543; 1893, page 102; and 1895, page 238.

How much influence the Institution of Mechanical Engineers is exerting, in connection with what has been justly called the "renaissance of inorganic and physical chemistry," may be gathered by comparing this series of Reports with some recent observations of Dr. Étard of the École Polytechnique. He has pointed out* that "one prominent fact stands out more and more in the researches in later years, and its manifestations deserve to be collected, discussed, and studied; this fact is the influence, not of the infinitely small, the word would be unsuitable, but of very small quantities—the microplasms, or chimi-ons of some kind. A persistent study of steel has enabled the chimi-onic influence of such quantities as 0·02 per cent. of carbon, silicon, or phosphorus to be recognised; such quantities are actually employed in metallurgy when varieties of steel possessing certain properties are required. This relation of carbon and iron, expressed in terms of atomic weights, would give a formula $Fe_{1000}C$; and whatever may be thought of this inadmissible formula, the relation of one atom of carbon to one thousand atoms of iron remains a fact. Are there many elements in whose atoms such actions are revealed? Their existence may be accepted, if the rapidity of motion is such as to permit a single carbon atom to act upon a pile of a thousand atoms of iron. Some say that carbon converts iron into steel in virtue of its small atomic volume, which permits it to lodge between the atoms of iron; but other elements also convert iron into steel under certain conditions. Is not the effect due to a disturbance, propagated longitudinally, in the habitual movements of the atoms of iron; which disturbance is introduced by the specific movement of the chimi-on, that is, of the added element?"

For the consideration of this question I have for many years been gradually collecting evidence; and the first instalment of it was embodied in the Bakerian Lecture† delivered before the Royal Society in February last, which was, in no small measure, an outcome of the work of this Committee.

In the series of researches of which a part is described in the present communication, an attempt has been made to ascertain how far the properties of metallic masses are dependent on atomic movement and molecular grouping. The mechanical properties of alloys of definite series of metals have therefore assumed less prominence than

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[*] Revue des Sciences pures et appliquées, September 1896, page 755.

[†] Philosophical Transactions of the Royal Society, 1896, vol. 187 A, page 383.

the principles which affect alloys generally; and the result has been that, although the course adopted hardly needs justification, the practical bearing of the investigation may have seemed to be somewhat remote. The devotion of years of labour, for instance, to tracing the relations of alloys to saline solutions, would appear at first sight to be of less practical importance than determining the mechanical properties of alloys by the aid of testing machines. Establishing the analogy between alloys and saline solutions has however been eminently fruitful in practical results; for it has enabled the mechanical properties of alloys to be explained, and even to be predicted. It has been easy to show that the property of liquation possessed by saline solutions while freezing—which consists in rejecting a certain quantity, often very minute, of a fluid portion of the mass, and distributing or relegating it to a definite position in relation either to the mass as a whole or to the individual crystals—is now recognised as being of fundamental importance in determining the mechanical properties of varieties of iron and steel and of alloys generally. This subject of liquation will always be identified with the work of the Alloys Research Committee, and its history is interesting. Its origin is French;* but much experimental work in this connection was published more than twenty years ago in a paper of my own;† and the present Report will contain references to the latest phases of the enquiry, which may also be claimed as the outcome of the labours of this Committee.

Attacking the problem of the constitution of alloys from the atomic point of view has moreover been fruitful in results; for it has enabled the influence exercised by the relative atomic volumes of the alloyed metals upon the mechanical properties of the mass of metal to be clearly revealed. It has in fact justified the view of our Past-President, Sir William Anderson, who initiated the work of this Committee, the original object of their investigation being to ascertain whether a connection could be traced between the mechanical properties of metals and the "periodic law" of Newlands and Mendeléeff (Proceedings 1893, page 102). With reference to this object, Professor Fessenden has lately published a remarkable lecture on "Some recent work on Molecular Physics," which he delivered before the Franklin Institute.* After a singularly appreciative reference to the experiments which gave rise to this series of Reports, he observes, "We see at once that, in general, the addition to a metal of large atomic volume of one whose atoms are small must increase the tensile strength of the former." He gives mathematical reasons why it should be so, and illustrates his conclusions by the lines shown in Fig. 1, Plate 1, which exhibit the relations between Young's modulus of elasticity and the atomic volume of metals, and between the rigidity of metals and their atomic volume. In Fig. 2 he traces the relation between the tensile strength of metals and their atomic volume. It may now, I think, be accepted as proved, that the influence exerted by an element added to a mass bears a direct relation to its atomic volume. This appears to be also true within the limit of elasticity; and this is precisely the point upon which our Past-President, Professor Kennedy, has urged that it is desirable to obtain information. It is shown moreover by Professor Fessenden how readily the properties of a metal or an alloy may be disturbed by what, even to those who have experience of the extraordinary action exerted by traces of elements on masses of metal, appear to be insignificant causes. The original problem proposed for consideration by the Alloys Research Committee—"Are the mechanical properties of metals and alloys connected with their atomic volumes?"—has been definitely answered in the affirmative, not only in the course of the present series of researches, but by the experimental and theoretical work of physicists and mathematicians on the Continent and in America.

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* Levol, Annales de Chimie et de Physique, vol. xxxvi, 1852, page 193; vol. xxxix, 1853, page 163.

† Proceedings of the Royal Society, vol. xxiii, 1874-5, page 481.

I have reluctantly come to the conclusion that we are not in a position to deal adequately in the present Report with the great question of the behaviour of pure and impure metals within their elastic limit. Some considerations bearing upon this subject will however be found in pages 53–5. As regards the immediate future, I am of opinion that the nature of what may be called "solid solutions" of metals must be more carefully studied than has hitherto been the case. When this has been done, it will be desirable to continue the investigation of the influence of the atomic volume of elements, within the elastic limit of the mass and beyond it. It should however be borne in mind that the system of recording pyrometry, which was devised for this Committee and is now widely adopted, has for the first time enabled a clear view to be obtained of the constitution of the metallic alloys. It will be necessary to place on a firmer basis our knowledge of the mechanical constitution of metals and alloys, as revealed by the pyrometer and the microscope, before attempting to explain how "structure" is built up of the ultimate atoms or molecules of the metals.

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* Journal of the Franklin Institute, September 1896.

Brasses.—The work on the alloys composed of copper and tin, begun in 1892 and published in the Third Report (Proceedings 1895, pages 252 and 269–279), was followed by a similar investigation of the copper-zinc series, which includes every variety of brass, and therefore possesses much industrial importance. It has been claimed that no alloy except steel exhibits such extreme diversity of mechanical properties as the brasses; but in this respect they hardly equal the variations exhibited by the copper-tin alloys, which range in strength from 18 tons per square inch down to friable masses, and in colour from reddish yellow to grey blue; while trustworthy ordnance, sonorous bells, or brilliant mirrors, may severally be produced from suitable members of the series.

The investigation of the copper-zinc series was conducted on the same general lines as that of the copper-tin alloys: that is, by employing the recording pyrometer (Proceedings 1893, pages 132–4) for obtaining a complete series of curves, which indicate what takes place during the cooling and solidification of a large number of alloys composed of copper and zinc in varying proportions. As in the copper-tin series, some of these curves have been so arranged in Plate 2 that the point at which each curve intersects the horizontal "composition" line PP marks the percentage of copper and of zinc in the alloy represented by the curve. It is unnecessary to remind readers of these Reports how seldom it happens that an alloy solidifies sharply or at one temperature, as water does. In alloys there are generally at least two freezing points. As a molten alloy cools, the different stages of solidification are clearly indicated by changes in the direction of the curves. The position of these changes in respect to composition, and their mutual relations in the entire series, are emphasized by dotted lines *b*B, *c*C, *d*D, *e*E, *ee*, and by the curved line ABCDEF, which connect similar freezing points in adjacent alloys. The term "freezing-point curve," applied to these dotted lines, has now taken a firm place in scientific literature,* though it must be borne in mind that the designation "freezing point" is applied to each of the various temperatures at which the different groups of constituent metals solidify. As in the copper-tin series, these curves have been considered in relation to the mechanical properties of the alloys; and they throw a good deal of light on the difficulties which are met with in working the varieties of brass, and point to the adoption of methods for overcoming these difficulties. It will be necessary however to discuss the meaning of the various points on the curves, before dealing with the industrial significance of the results; and for the present it will be better to trace the relation of this investigation to other work which has been published recently in France.

The research on the brasses, which forms one of the subjects of this Report, was begun nearly two years ago; and while it was nearing completion, M. Charpy† presented to the Société d'Encouragement the first Report of the "Commission des Alliages." It is entirely devoted to the copper-zinc alloys; and his conclusions, which are of much interest and importance, may be briefly summarised as follows. The tenacity of the brasses is greatly increased by working; and annealing these alloys is effective at lower temperatures than has hitherto been supposed: annealing may in fact begin at so low a temperature as 430° C. or 800° F., and is very efficacious at 500° C. or 900° F. Heating brasses to 900° C. or 1,650° F. causes a rapid diminution in the extensibility of the alloy; and in the commercial alloys, which contain 0·15 per cent. of tin and 0·2 per cent. of lead, this effect, which is technically known as "burning," is produced at a temperature below 800° C. or 1,450° F.

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* Heycock and Neville, Proceedings of the Royal Society, 1896, vol. lx, page 160.

† Bulletin de la Société d'Encouragement, 1896, pages 180-234.

With reference to the effect of annealing at low temperatures, it may be pointed out incidentally that M. Osmond* and myself have recently shown that gold alloyed with antimony, and forming a mass which on cooling reveals large crystalline planes, may be annealed at so low a temperature as 250° C. or 480° F. The result is that the original structure entirely disappears, and the mass becomes minutely granular, no traces remaining of the large crystalline planes; the effect may be compared with that of annealing cast steel at about 800° C. or 1,450° F.

If attention be limited to the copper-zinc alloys which admit of industrial application—namely such as range from copper alloyed with a minute proportion of zinc to copper alloyed with 45 per cent. of zinc—it will be found that the limit of elasticity, the resistance to penetration, and the hardness, increase continuously with the proportion of zinc. The extensibility also increases with the percentage of zinc, and attains its maximum in the alloy containing 30 per cent. of zinc, and then decreases rapidly. The compressibility and the reduction of sectional area increase with the percentage of zinc, attaining a maximum with 30 per cent. of zinc, after which they decrease. The tenacity increases with the proportion of zinc, attains a maximum with about 45 per cent. of zinc, and then decreases rapidly. The alloys become fragile when they contain 50 per cent. of zinc.

Some of M. Charpy's curves have been plotted in Plate 3, which gives the freezing-point curves of the copper-zinc series obtained for the Alloys Research Committee. As M. Charpy justly remarks, by varying the proportions of zinc between 30 and 43 per cent. a series of brasses may be prepared, which possess such diverse properties that different members of the series represent almost distinct metals, although the range of variation in composition is limited. The most malleable of the series elongates about 60 per cent., and its tensile strength is 17·45 tons per square inch, while one with 40 per cent. of zinc still elongates 40 per cent. with a strength of 23·8 tons per square inch. By adjusting the softening effect due to annealing, and the strength produced by working, it is easy to increase the tenacity of bars and sheets to 38·09 tons per square inch, and to attain even greater strength in the case of wires. It is satisfactory that the evidence now submitted to the Alloys Research Committee is equally significant and important. M. Charpy's curves represent respectively tenacity and extensibility, and from these has been plotted the curve marked "work done" in extension and fracture. Thurston* has also studied the mechanical properties of the copper-zinc series of alloys, and his curves are plotted in Plate 3. These curves have been arranged under the freezing-point curve of the copper-zinc series in this diagram, in which the horizontal distances or abscissæ are percentages of copper and of zinc. It will be evident that the entire series of curves are closely related. In order to make this clear, a brief explanation of the freezing-point curves and of the eutectic alloys is necessary.

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* Bulletin de la Société d'Encouragement, 1896, pages 1136–1152.

Eutectic Alloys.—In the curves which represent the cooling and solidification of most alloys, there are usually several points at which the direction of the curve changes, sometimes becoming approximately horizontal for a short distance. The first or uppermost of these halts or breaks usually represents the falling out of a more or less pure metal, or of some compound of the metal, from the cooling alloy. A second and sometimes a third break will be found on most of these curves; and these breaks indicate the solidification of a eutectic alloy, that is, a fusible metallic "mother liquor" or bath, which solidifies at a definite temperature. In the copper-zinc series there are several of these eutectic alloys; and the initial freezing points lying on the line ABCDEF in Plate 2 represent the solidification of copper, of zinc, and of certain compounds of copper and zinc. In the industrial brasses, which never contain more than 45 per cent. of zinc, only three of the freezing points need now be referred to; but the scientific interest of the rest will be considered later on. Reference to a particular instance will serve to make clear the meaning of the curves.

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* Treatise on Brasses, Bronzes, and other Alloys; New York, 1893, page 366.

If in the freezing-point curves, Plate 3, representing the copper-zinc alloys, a vertical line be drawn, say from the point which marks 71 per cent. of copper, it will be seen that it encounters two freezing points, one at 952° C. or 1,746° F., and a lower one at 896° C. or 1,645° F. This means that the cooling curve obtained by the autographic recorder for the alloy containing 71 per cent. of copper had two points of solidification; and by the aid of a method which is fully described in page 45 it is possible to determine what constituents of the alloy fell out of solution at each of these two points. In this particular case they may be taken to be respectively copper, and the eutectic alloy of copper with the compound Cu Zn of copper and zinc: that is to say, the most fusible alloy that copper can form with Cu Zn, which alloy contains about 63 per cent. of copper. It will be understood that in Plate 3, which epitomizes all the cooling curves of the copper-zinc series, the points marked are those which in any given alloy were actually found in the autographic record of its cooling. Thus in the alloy containing 68·6 per cent. of copper (page 44) three distinct freezing points were detected; whereas in the alloy containing 62·6 per cent. the two upper points are blended into a single point occurring at 892° C. or 1,638° F., while the lower point at 450° C. or 842° F. still remains. It will be evident therefore that a curve drawn through a single freezing point for each alloy of a series cannot be claimed as complete. Such a curve is far from representing what actually happens during the solidification of the alloys of a given series, because comparatively few alloys become solid at a single point, while many have three points of solidification, and some have four or even five.

Guthrie* introduced the designation "eutectic" alloy to denote the most fusible alloy of two or more metals, comparing it to the mother liquor of a salt solution, which remains fluid after the bulk of the salt has crystallized out. The recording pyrometer shows that as regards alloys the case is really far more complicated. Many alloys consist, when fluid, of more than one solution; and each of the several solutions leaves, on cooling, a solid deposit and a fluid mother liquor. These mother liquors however do not usually unite with one another; and a complicated set of conditions is established, when the temperature has fallen sufficiently low for the whole mass to become solid. Each of these metallic mother liquors is a eutectic alloy, and may be included in the definition of eutexia actually given by Guthrie, although he does not appear to have been aware that there might be more than one eutectic in a single series of alloys. A "series" is here taken to mean all the possible unions which can be effected between two metals. Some alloys, such as those upon which Guthrie worked —the lead-tin for instance—are of a simple character, and when fluid have only one eutectic alloy, that is, the deposits fall out from a single mother liquor. All the alloys which are used for the sake of their strength appear to be highly complicated. Thus in the alloys of copper and zinc there are at least four eutectic alloys, and in the copper-tin series there are at least six.

It has been shown by Guthrie and others that the composition of eutectic alloys does not in general correspond with simple atomic proportions of the component metals; and indeed there are theoretical reasons for supposing that a eutectic alloy cannot possibly be a chemical compound. The higher point on the freezing-point curve, that at which the excess of either metal begins to solidify, indicates the solubility of one metal in the other, since it occurs at the temperature at which the solution is exactly saturated. Thus the freezing-point curve A B sloping down from the lead end of the lead-tin series in Plate 4 indicates the solubility of lead in tin; while the curve C B sloping down from the tin end indicates the solubility of tin in lead. Where these curves meet at B, it will be obvious that both lead and tin will be deposited simultaneously by further cooling, and that the composition of the residual fluid alloy will remain unchanged. Thus the whole of this residual alloy solidifies at a single temperature, 180° C. or 356° F., and the lead and tin crystallise out side by side. There is therefore much reason for believing that, when solidified, the eutectic alloy indicated by the line *a c* is merely an intimate mixture of the component metals.

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* Philosophical Magazine, vol. xvii, 1884, page 462.

Melting or Freezing Point.—The upper point on a cooling curve, at which the metal in excess begins to crystallise, is the point which has usually been termed the "melting" or "freezing" point; and difficulty has naturally been experienced in deciding what part of the long range of temperature, during which solidification takes place, should be called the true melting or freezing point of the alloy. In the previous Reports alloys with more than one freezing point have been referred to. The temperature at which one constituent begins to crystallise out was called the higher freezing point; and the temperature at which the eutectic alloy solidifies was called the lower freezing point. It may appear at first sight as though these points must be merely the beginning and ending of one continuous process of solidification. Even if this were so, it would be well to indicate both the beginning and the ending of the solidification of an alloy, and not merely a sort of rough mean; but as, in the majority of cooling curves, the initial and eutectic freezing points are indicated by separate and distinct evolutions of heat, they may rightly claim to be separate, and not merely stages in a single operation. That this must be so may be deduced from any freezing-point curve; for it can easily be shown that, for any particular alloy, the greater part of the metal which is in excess crystallises in a short range of temperature below the initial freezing point. Thus, to take a simple instance from the lead-tin series of alloys, Plate 4, the alloy which contains 90 per cent. of lead begins to freeze at 290° C. or 554° F., and has a eutectic alloy at 170° C. or 338° F. The eutectic alloy, comprising one-fourth of the whole mass, freezes entirely at 170° C.; and of the remainder, which is pure lead, two-thirds freeze in the 25° C. (or 45° F.) which intervene between 290° and 265°, leaving only one-third to crystallise out during the remaining 95° C. (or 171° F.) of fall. It is therefore justifiable (1) to say that these alloys have two true freezing points; and (2) to adopt the *commencement* of the upper freezing range and the eutectic freezing temperature as the two significant points to record; while (3) for industrial purposes, such as the casting of alloys, it might be well also to indicate either the temperature at which the mass appears to solidify, or that at which any particular fraction, say one-quarter of the alloy, has solidified.

The eutectic alloy of lead and tin contains a considerable proportion of each metal; and therefore the eutectic freezing-point line *ac*, Plate 4, which passes through the freezing point B of the eutectic alloy of the series, extends both right and left of this point. In most alloys however the horizontal line can be detected only on one side.

The fact that the lead-tin series has more than one freezing point is of industrial importance, for on it depends the facility with which an artificer can "wipe a joint" with plumber's solder. The latter contains 66 per cent. of lead, and its pasty condition when used is due to the fact that it has two widely separated points of solidification, the alloy consisting of granules of solid lead in a fluid mother liquor.

Mechanical Properties of the Brasses, considered in relation to their Freezing-Point Curve.—Plate 3.—With the above prefatory remarks it is possible to trace the relation between the freezing-point curve of the brasses, and the curves which represent their mechanical properties of tenacity and extensibility. In Plate 3 the abscissae show the percentages of copper and of zinc for all the curves; the analyses are given in Table 8, page 44. The ordinates represent temperature for the freezing-point curves, and tenacity and extensibility for the remaining curves. It will be evident at a glance that all these curves are directly and closely related to one another. The fact that a complete freezing-point curve does not consist merely of a curve drawn

TABLE 8.—*Freezing Points of Copper-Zinc Alloys.*

Figures in brackets indicate small halts in the cooling curves.

Percentage of		Temperatures of Freezing Points.							
Copper.	Zinc.	Centigrade.				Fahrenheit.			
100·0	0·0	1082				1980			
96·2	3·8	1075				1967			
94·7	5·3	1076				1969			
86·1	13·9	1032				1890			
80·1	19·9	1008				1846			
76·3	23·7	980				1796			
75·4	24·6	980,	(473)			1796,	(883)		
71·7	28·3	958,	(900)			1756,	(1652)		
70·9	29·1	952,	(896)			1746,	(1645)		
68·6	31·4	935,	883,	(450)		1715,	1621,	(842)	
66·4	33·6	918,	893			1684,	1639		
66·2	33·8	913,	882			1675,	1620		
63·0	37·0	908				1666			
62·6	37·4	892,	(450)			1638,	(842)		
59·7	40·3	886				1627			
59·7	40·3	894,	(460)			1641,	(860)		
59·6	40·4	889,	(450)			1632,	(842)		
52·1	47·9	878,	463			1612,	865		
50·2	49·8	880				1616			
48·1	51·9	855,	460			1517,	860		
47·4	52·6	870,	(470)			1598,	(878)		
47·0	53·0	852,	(462)			1566,	(864)		
45·8	54·2	855,	(470)			1571,	(878)		
41·2	58·8	840				1544			
38·5	61·5	823				1513			
34·6	65·4	816				1501			
32·8	67·2	803				1477			
29·2	70·8	786,	(682),	(531),	(450)	1447,	(1260),	(988),	(842)
27·3	72·7	766,	680,	(535)		1411,	1256,	(995)	
24·3	75·7	740,	680,	565,	554	1364,	1256,	1049,	1029
24·0	76·0	741,	691,	569,	550	1366,	1276,	1056,	1022
23·2	76·8	732,	680,	587,	(554)	1350,	1256,	1089,	(1029)
22·8	77·2	729,	586.	(555)		1344,	1087,	(1031)	
20·9	79·1	712,	(683),	590,	(477)	1314,	(1261),	1094,	(891)
20·0	80·0	705,	590			1301,	1094		
19·1	80·9	695,	590			1283,	1094		
17·9	82·1	680,	591			1256,	1096		
16·6	83·4	666,	588,	(470)		1231,	1090,	(878)	
15·0	85·0	657,	596			1212,	1105		
14·3	85·7	633,	590,	(440)		1171,	1094,	(824)	
12·2	87·8	609,	586,	419		1128,	1087,	786	
12·1	87·9	592,	419			1098,	786		
11·1	88·9	588,	583,	420		1090,	1081,	788	
10·9	89·1	583,	570,	420		1081,	1058,	788	
10·6	89·4	579,	419			1074,	786		
7·9	92·1	547,	418			1017,	784		
7·2	92·8	537,	420			999,	788		
3·6	96·4	(465),	419			(869),	786		
1·9	98·1	(425),	419			(797),	786		
1·8	98·2	420				788			
0·0	100·0	419				786			

through a single freezing point in each alloy of the series has already been referred to; and it has been explained that many of the alloys have more than one freezing point. Hence the curve is one having horizontal branches, *b*, *c*, *d*, and *e*, which represent eutectic alloys. The main curved line A B C D E F represents the initial freezing points of the several alloys in the series. Looking at the curves which represent the mechanical properties of the brasses, it is seen that on adding zinc to copper these properties change somewhat abruptly before the alloy containing 50 per cent. of zinc is reached; and further that tenacity and extensibility both fall to a very low point when 50 per cent. of zinc is exceeded. The explanation of the relation between the freezing-point curve and the curves representing the mechanical properties requires a knowledge of the true significance of the points on the former curve; and this is afforded by chemical analysis of the portion of the alloy which solidifies at each point. It is first necessary to separate from each alloy in the series its own particular eutectic alloy; and this separation may be readily effected by squeezing away the fluid portions in a press, as shown in Fig. 7, Plate 6. The alloy under examination is placed in the steel cylinder C, which is fitted with two loose steel plungers PP, each about ½ inch diameter. The whole is placed between the jaws of a hydraulic press, and a pressure of about half a ton per square inch is maintained on the ends of the plungers. The cylinder C is then slowly heated, the temperature at any moment being measured by the thermo-couple T, which is placed in a hole drilled in the cylinder. At a certain definite temperature part of the alloy will liquefy, and can be squeezed out between the plungers and the wall of the cylinder. The temperature is noted at which the alloy is sufficiently liquid to be extruded. The heat is then raised, and a further portion of the alloy can sometimes be separated. Finally a comparatively infusible residue is left. These several portions are then analysed. In some cases it is found to be desirable to subject the extruded portions to a second treatment in the compressing cylinder. The points on the line AB, Plate 3, represent the solidification of metallic copper which is approximately free from zinc. The subsidiary points at *b*B on the othe hand prove to represent true eutectic alloys containing about 63 per cent. of copper, in which the two metals do not appear to be related in any simple atomic proportions. The points between B and C represent the solidification of the compounds Cu Zn and $Cu Zn_2$; and the existence of the latter as a true compound has already been established by Laurie* on electro-chemical grounds. Both these compounds are found to be very brittle; and all the copper-zinc alloys in which either of these compounds forms the main constituent are also very brittle. The eutectic alloys of which the freezing points lie on the line *b*B probably consist, when solidified, of an intimate mixture of copper with Cu Zn; while that part of the line BC which is immediately to the right of B also represents the solidification of the compound Cu Zn and of uncombined copper. There is a larger proportion of Cu Zn than corresponds with the eutectic alloy; and if no other compound of zinc were present, the line BC would turn upwards from B, as it does in the alloys of certain other metals—the copper-antimony series, for instance—and would represent the solidification of the excess of Cu Zn, while the eutectic line *b*B would be continued horizontally to the right of B. It is not found here to continue in this way, because the compound Cu Zn is soluble in one or more of the other compounds rich in zinc, which increase in importance to the right of B as the proportion of zinc is increased. Near the point B the alloys have one main freezing-point, and are almost free from subsidiary eutectic alloys. The dominant fact disclosed by these curves is that the maximum strength in the series of cast brasses occurs in the alloy containing 60 per cent. of copper; and it will be observed that this alloy has practically only one freezing-point, namely at B. Further additions of zinc cause a rapid diminution of tensile strength and extensibility; and the explanation would seem to be that in these alloys the compound Cu Zn is unaccompanied by free copper.

It will also be seen in Plate 3 that in this series the apex of the curve representing extensibility coincides with the first appearance

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[*] Journal of the Chemical Society, vol. 53, 1888, page 104.

of the upper eutectic *b* (see page 40), which falls out from the alloy that contains 71 per cent. of copper. This eutectic, as already stated, probably consists of a mixture of copper with the compound Cu Zn. The mixture of these soft and hard substances produces great strength, as is evident from the fact that the strongest alloy of the series consists almost entirely of this eutectic; but the presence of the eutectic naturally diminishes the extensibility of a mass which contains more than a small amount of it. Thurston's tensile tests in Plate 3 were made on cast brasses; Charpy's test pieces were completely annealed; and the experiments made for this Report were on worked rods. It is noteworthy that both the annealing and the working of cast brass materially increase its strength; and this fact is of industrial importance, as it suggests that for certain purposes a brass containing nearly 50 per cent. of the cheaper metal zinc may by suitable treatment be endued with properties which render it as useful as one richer in copper; its extensibility however would be small. Although brass containing from 60 to 70 per cent. of zinc is extremely weak, further additions of zinc are accompanied by a partial return of strength, which appears to be in some way connected with the presence of free zinc; and the eutectics *c* and *d* and *e* are formed by compounds that appear to be less brittle than the compounds Cu Zn and Cu Zn_2 which are so hurtful in the alloys containing less zinc. Each apex of a curve representing mechanical properties seems to be in some way connected with a point on the freezing-point curve where the points of solidification tend to unite, as at B and C and D. In the copper-zinc series the connection is complicated by the simultaneous presence of more than one eutectic; but in the lead-tin series shown in Plate 4 the maximum strength is possessed by the eutectic alloy of the series, and in the lead-tin series there is only one such alloy. In the copper-zinc series this connection between a maximum strength and the union of the constituents of a given alloy in a single point, though generally clear, is sometimes masked by the wide range through which the eutectics extend; but where the eutectics die away, as at *b*, *c*, *d*, *e*, it is remarkable that there are corresponding falls in the tenacity curve.

Influence of a Eutectic on certain properties of Alloys.—It has long been known that the addition of a comparatively small amount of iron to certain alloys of copper and zinc increases their strength in a remarkable way, as is the case in "Sterro" and in Aich's metal. The cause has hitherto been obscure; but a comparison of the cooling curve B, Plate 5, of a copper-zinc alloy, with the cooling curve A of the same alloy after the addition of 1½ per cent. of iron, at once disclosed the cause of the increased strength. The alloy selected contained 61 per cent. of copper and 39 per cent. of zinc; and in the absence of iron there was a low eutectic point *c* in the cooling curve B at about 450° C. or 842° F., evidently due to the presence of a eutectic, which constituted a source of weakness. The added iron however entered into combination with the eutectic, forming with it a less fusible compound; for a cooling curve A then showed that the low eutectic point was absent, and that the source of weakness had been removed. Moreover the main solidifying point *a* of the Aich's metal was higher than that *b* of the brass: which in itself is an indication of augmentation of strength. The facts thus established are probably of wide importance in metallurgical practice; and where strength is desired, it would appear to be advisable, whenever a cooling curve reveals the presence of a low eutectic in an alloy, to add some third metal which will diminish the fusibility of the eutectic. Aich's metal, when compared with brass of the same composition but without the 1½ per cent. of iron, is greatly superior in strength. If it owes this superiority to the fact that a eutectic alloy does not remain fluid as the mass cools, it might be anticipated that the relatively high tenacity of Aich's metal would be maintained at temperatures at which the brass would become weak. Table 9 shows that this anticipation is justified. It may be confidently asserted that the obliteration of a eutectic alloy, which is effected by the addition of a small quantity of some other metal, affords the means of explaining much that has hitherto been obscure as regards the strength of alloys. Only those eutectics however, which are much more fusible than the mass of the alloy wherein they occur, are sources of weakness. The

TABLE 9.—*Tenacity of Brass and of Aich's Metal.*

Temperature of test.		Tenacity, per square inch.			
		Brass.		Aich's Metal.	
C.	F.	Lbs.	Tons.	Lbs.	Tons.
20° =	68°	46,330 =	20·7	57,300 =	25·6
100° =	212°	30,550 =	13·6	49,610 =	22·2
200° =	392°	28,300 =	12·6	40,200 =	17·9
250° =	482°	23,400 =	10·4	35,500 =	15·8
300° =	572°	16,310 =	7·3	27,920 =	12·4
350° =	662°	15,200 =	6·8	25,000 =	11·2
400° =	752°	*15,915 =	7·1*	21,800 =	9·7
450° =	842°	8,080 =	3·6	11,430 =	5·1
500° =	932°	6,300 =	2·8	9,192 =	4·1

* Increased tenacity due to experimental irregularities.

Composition of Brass:—Copper 61·2, Zinc 38·8 per cent.

Composition of Aich's Metal:—

Copper 59·8, Zinc 37·9, Iron 1·5, Tin 0·8 per cent.

presence of eutectics with comparatively high melting points usually increases the strength of an alloy, although it diminishes its extensibility.

This assimilation of two constituents of a fluid alloy which do not naturally mix, by the intervention of a third metallic solvent, is moreover of great industrial importance. A curious instance of its usefulness arose in connection with the alloys of gold which now reach this country from South Africa, where the extraordinary development of certain processes used for extracting gold from its ores has been attended with singular results. Ingots of gold now imported into this country are often alloyed with base metals to an extent which has hitherto rarely been met with in metallurgical industry. The base metals associated with the gold in these ingots are usually lead and zinc; and the presence of these metals has given rise to unexpected difficulties in estimating the value of the ingots. The difficulties arise from the peculiar distribution of the precious and of the base metal, which renders it impossible to estimate the value of the ingots by taking, by any of the well-known methods now in use, the pieces of metal required for assay. An ingot of gold, for instance, of the following composition

Gold	61·7
Silver	8·1
Lead	16·4
Zinc	9·5
Copper	4·0
Iron	0·3
	100·0

proved, when the gold was actually separated from it, to be really worth £1,028, while its value, as indicated by assay pieces taken in the usual careful manner, was only £965, or a difference of no less than £63 on a single ingot. This subject was investigated by Colonel E. Matthey,* who showed that the distribution of the gold in the mass was mainly determined by gravity. An ordinary cooling curve taken on such an alloy disclosed the existence of several subordinate freezing points, notably one which occurred at 407° C. or 765° F. and was probably due to the zinc eutectic of the series. The main solidifying point of the mass was at 655° C. or 1,211° F. The alloy contained 8·1 per cent. of silver; and after remelting such alloys with the addition of silver so as to increase the proportion of the latter to 15 per cent., a cooling curve was obtained in which the subsidiary zinc eutectic point could no longer be found, and the mass proved to be practically uniform in composition, and there was no difficulty in determining its value by an assay piece cut in the ordinary way. The general conclusion seems to be that, if the base metal does not exceed 30 per cent., half that amount of silver will combine with it, and will prevent the formation of a eutectic which would destroy the uniformity of the mass. A singular instance is thus presented of the value of the work of this Committee being manifested in an unexpected direction.

General observations on investigation of Alloys.—The work which has been conducted during the last few years by the aid of the recording pyrometer has served to show that the molecular changes which take place during the cooling of alloys are more complicated than they have generally been supposed to be. Until quite recently, even those who recognised the existence of more than one freezing point in an alloy nevertheless appeared to consider that the initial point of solidification was practically the only one which need be taken into account. Even now all the freezing-point curves which have been published, with the exception of those given in the present series of Reports, afford no indication of the existence of more than one freezing point in the case of each alloy of a series. In order to understand the constitution of any series of alloys, it is absolutely necessary to determine the position of all the points of solidification which are revealed as the alloys cool down. This necessity may be exemplified by some beautiful curves recently published by M. Gautier,* which were plotted by directly observing the indications of the pyrometer. Cognisance was not taken of more than one halting place in the cooling of each alloy; hence not only are the subsidiary eutectic points ignored, but in some cases the main eutectic alloys appear to have escaped recognition. Thus in the freezing-point curve of the silver-zinc series, Fig. 8, Plate 6, M. Gautier concludes from his curve that zinc is "isomorphous" with a certain silver-zinc compound *a*: that is to say, the intermediate alloys freeze entirely at the points given by the line *a b*. Autographic records however reveal the presence of a eutectic *b c*, having a slightly higher melting point than that of zinc, which shows that the metals in the silver-zinc series of alloys can hardly be isomorphous. Silver-zinc alloys are of great importance in connection with the desilverization of lead by zinc, a process which is now so widely adopted. In the same way M. Gautier gives as the freezing-point curve of the copper-lead series the dotted curve *ab*, Fig. 9, of the same kind as that of copper-bismuth; whereas the autographic records show it to consist of two parallel lines *cd* and *be*, the upper of which is joined to the melting point of copper by the line *af*, and falls rapidly at the lead end to meet the lower line, thus proving how little soluble copper is in lead.* The freezing-point curve of the copper-lead alloys, obtained by autographic records, is given on a larger scale in Plate 7.

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* Proceedings of the Royal Society, vol. lx, 1896, page 21.

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* Bulletin de la Société d'Encouragement, 1896, pages 1293–1318.

The action of impurities is clearly evident in connection with these subordinate eutectic points, as was shown in a decisive way in the series of curves given in Fig. 7, Plate 39, of the last Report to this Committee,† where it was demonstrated that in a mass of gold the presence of a fusible alloy of bismuth and gold which solidifies at 229° C. or 444° F. greatly reduces the strength of the gold. In some cases the foreign bodies remain in the mass either partly or wholly as solidified solutions, the impurities being dissociated into their atoms in both the solid and the liquid mass. Evidence on this point is given in a joint paper‡ by M. Osmond and myself, which will be dealt with in the next Report of this Committee in connection with the work of other experimenters. The influence of the presence of fusible eutectics on the strength of materials will probably in future be the dominant question in studying the influence of "traces" upon masses; it is to be hoped that it will not be lost sight of by the eminent investigators in Germany who are devoting attention to the mechanical properties of alloys. In this connection reference may be made to the work of Professor Martens at the Royal Technical Experimental Works in Berlin.§ The Royal Technical Research Commission in that city has arranged an elaborate programme for testing the strength of metallic copper, of which only the first part, dealing with the influence of the method of experimenting and with the condition of the material, has as yet been published. Some highly valuable information, respecting the strength of metallic copper, and the working stresses to which the metal may safely be subjected in industrial use, has already been obtained. The data now furnished relate only to one variety of commercial copper; and Professor Martens points out that "a knowledge of the effect of the admixture of foreign ingredients on the properties of copper" will have to be acquired. It is here however that the difficulties begin in the case of copper, or in that of any metal in which the effect of added elements has to be studied. For instance, assuming that copper of a high degree of purity, as indicated by chemical analysis, gives certain constants—limit of elasticity, modulus of elasticity, tensile strength, and reduction of sectional area—it might at first appear that nothing could be simpler than to test the mechanical properties of the same copper, to which say 1–10th of one per cent. of lead has been added. But the question at once arises, what has happened to the metallic lead? Has it remained free? has it united with a certain amount of the copper to form a fusible eutectic alloy? has it abstracted oxygen from the copper, becoming itself oxidised? has it united with the copper to form a "solid solution"? or lastly, does it form a true chemical compound with the copper? It is only reasonable to ascertain what has probably happened to an added element, before making elaborate tests on a metal in which chemical analysis shows only that a certain amount of the foreign element is present, but is incompetent to disclose the condition in which it exists in the metal.

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* The melting points of copper, silver, zinc, and lead, employed by M. Gautier, differ slightly from those adopted in Figs. 8 and 9, which correspond with the scale of temperature used in this Report.

† Third Report, Proceedings 1895, page 238.

‡ Philosophical Transactions of the Royal Society, 1896, vol. 187 A, page 417.

§ Mittheilungen aus den Königlichen Technischen Versuchs-anstalten zu Berlin, parts 2 and 3, 1894.

Elastic Limit.—The elastic limit has hitherto been defined as follows:—(*a*) the load at which the material under stress just fails to resume its original size or shape when the load is removed; and (*b*) the load at which the stress and strain cease to be proportional, that is, at which Young's modulus ceases to be constant. Under both these definitions the detection of the limit, and the magnitude of the corresponding load, depend on the accuracy of the instruments used for measurement. The more delicate the instruments, the smaller will be the apparent value of the elastic limit of the material. There is ample evidence to show that with sufficiently delicate apparatus the smallest load will produce permanent set. The problem is therefore reduced to the detection of the load at which a marked departure from Hook's law takes place. Hartmann* has recently pointed out that the restoration of a piece of metal to its original form after distortion is the result of forces called into play by the distortion. He considers a stressed material to be "polarised" in the direction in which distortion takes place; and the polarised material tends to become depolarised by returning to its original form. In this connection it is easy to see why, as Bauschinger has experimentally shown to be the case, extremely small loads are capable of producing permanent set. The production of such a polarised condition, that the molecular grouping shall be best calculated to resist a particular stress, explains the advantage of employing columns which have been stressed beyond their elastic limit, care being taken to prevent flexure during the application of the load. It also explains the hardening effect produced by the "cold working" of metals and alloys. The difference between the change produced in a metal by excessive stress, and by alloying it with a small quantity of another metal of different atomic volume, is probably as follows. Excessive stress produces an intermolecular arrangement, that is, a polarized condition of the molecules; whereas alloying with another metal produces a change in the molecules themselves, that is, the arrangement of the atoms in the molecules is affected. Picturing the molecules in an isotropic medium as being uniformly distributed spheres, as in Fig. 10, Plate 6, having mutual attractions, the effect of longitudinal stress or of rolling will be to polarize them, as in Fig. 11; and it will be evident that, as Hartmann shows, the distortion will not take place in the direction of the applied force, but at an angle thereto, in the direction of the line of slip, as in Fig. 12. The forces acting on the material will consequently vary from point to point. After a certain amount of distortion produced by a small load, some of the molecules will be permanently displaced, and will be arranged as in Fig. 12; that is, the molecules will be moved from their position of stable equilibrium into some other position, also of stable equilibrium; and they will therefore not return on the removal of the load. The load at which any considerable number of them permanently assume a new position constitutes the elastic limit. The result will be that molecular slip will take place at an angle of about 45° to the direction of the line of stress, as has long been known to be the case. The lines of flow, known as the lines of Luders,* which are produced on the surface of well polished metals by stress, seem to afford clear evidence of this deformation of molecules; and seem to show that it takes place, not in the direction of the applied force, but according to Hartmann spirally, the lines being inclined at a certain angle to the direction of the force, Fig. 13. The subject is far from complete at present; but there is ground for hope that the action of the forces which resist the distortion of a solid body will sooner or later be clearly revealed, although at present it is only possible to consider their net result. As the deformation occurs in this special manner, the elastic limit as ordinarily measured depends to some extent on the angle made by the lines of flow with the line of applied force. Hartmann says that the elastic limit is reached when the applied force overcomes the force of cohesion which it calls into play. He connects "specific heat" with the elastic limit, saying that one increases as the other decreases; and Tomlinson has also pointed to this connection. Fessenden shows by the line already referred to, Fig. 1, Plate 1, that rigidity and atomic volume are closely connected; and as the investigations proceed, it seems to become more and more clear that the elastic limit of metals is directly influenced by the atomic volume of the added element. Experiments made with a view to determine the elastic limit must however be conducted with wires, as Lord Kelvin and others have shown.

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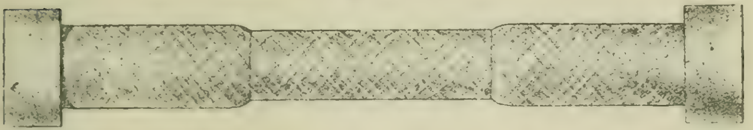
* Distribution des Déformations dans les Métaux soumis à des efforts; Paris, 1896.

Fig. 13.



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* The subject of Luders' lines has been treated recently in an interesting paper by M. C. Fredmond, in the Bulletin de la Société d'Encouragement, 1896, page 1218.

Diffusion of Metals.—When two metals are melted together, or when a fresh metal is added to two or more metals which have already been melted together, the question has often arisen, why is it that the resulting mass, when solid, possesses the uniformity which experiment proves it to have? If, for instance, a few pounds of ferro-manganese are thrown into a converter containing ten tons of fluid iron, the resulting ingots into which the fluid metal is cast are found to be singularly uniform in composition. Liquation may to some extent have affected the distribution of the elements in each ingot; but any one ingot will be found to contain approximately the same amount of manganese as any other. The fluid mass in the converter cannot have owed its uniformity in composition solely to the mechanical agitation, which in one way or another aided the blending of the constituents. The result was influenced by the molecular mobility of the metals, which when dissolved in each other become, by a spontaneous process, spread or diffused uniformly. This is true of many alloys; and the spontaneous spreading or diffusion may be studied best in those in which the uniformity of composition does not become disturbed by liquation when the solidification of the mass is taking place. In approaching the consideration of this subject, it is important to remember that the laws which govern the diffusion of salts in water have already been carefully examined, and are well understood. Common salt or sugar, placed at the bottom of a vessel of water, would soon be dissolved, and would spread, in virtue of its own molecular movement, through the mass of the water with absolute uniformity; but, as Graham showed, the rate of diffusion is greatly increased by a small rise in temperature. It seems evident therefore that the diffusion of molten metals would be greatly influenced by the necessity for working at the high temperatures required to keep them melted; and certain experiments made by myself fourteen years ago had to be abandoned at the time for want of some means of measuring and recording the temperatures employed. The provision of the recording pyrometer, which was the direct outcome of the work of this Committee, enabled the investigation to be resumed; and the results have recently been communicated to the Royal

Society, and formed the subject of the Bakerian Lecture* for the past year. A description of the apparatus employed and of the precautions adopted would be out of place here; but the subject possesses so much industrial interest that a brief indication of the nature of the experiments should not be omitted. The various metals, of which the diffusion had to be studied, were placed at the bottom of tubes afterwards filled with molten lead; and the results of the diffusion, during twenty-four hours, of platinum and of gold through fluid lead contained in tubes placed side by side and heated to a temperature of about 500° C. or 900° F., are represented in Fig. 14, Plate 6. The columns marked gold Au and platinum Pt represent the actual length and diameter of the two columns of fluid lead. The spheres represent the sizes of the buttons of gold and of platinum extracted from the several sections, shown by the horizontal lines, into which the columns of lead were divided by a cutting tool after the metal had been allowed to solidify. In the curves, which are marked respectively gold and platinum, the vertical ordinate represents the *distance* through which diffusion takes place, and the horizontal abscissa the degree of concentration. Each of the metals, gold and platinum, which diffused into the fluid column of lead, occupied, in the form of an alloy with lead, the length *a d* of the tube; and in both cases the initial concentration of the alloy from which diffusion proceeded was the same, denoted by *a c*: so that the area *a c e d* represents the total amount of gold or platinum employed in the experiments, the whole quantity of either metal being originally below the line *d e*. The final state of complete uniform diffusion would be represented by the area *a b g f*, which is the same as *a c e d*, since the quantity of gold or platinum remains unaltered. In the same manner the area *a y x f* would represent the varying distribution of the gold at the end of the experiment; and consequently, in experiments which have lasted for equal times, the nearer the curve *y x* approximates to the line *b g*, the more rapid is the diffusion of the metal it represents. The general results may be grouped in the following Table 10, page 58:—

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* Philosophical Transactions of the Royal Society, 1896, vol. 187 A, page 383.

TABLE 10.—*Diffusion of Metals in Metals.*

Diffusing Metal.	Solvent Metal.	Temperature C.		F.	Relative Diffusibility in 24 hours.
Gold	Lead	492°	=	918°	3·00
,, ...	,,	,,			3·07
Platinum . . .	,,	,,			1·69
,, . . .	,,	,,			1·69
Gold	,,	550°	=	1,022°	3·18
Rhodium . . .	,,	,,			3·03
Gold	,,	555°	=	1,031°	3·19
,, ...	Bismuth	,,			4·52
,, ...	Tin	,,			4·65
Silver	,,	,,			4·14
Lead	,,	,,			3·18

It will be seen that gold diffuses more rapidly in bismuth and in tin than it does in the heavier metal lead. The continuation of these experiments has led to the recognition of the remarkable fact that diffusion of metals can readily be measured not merely in molten but in *solid* metals. It is certainly remarkable that gold—placed at the bottom of a cylinder of lead three inches high, and heated to only 200° C. or 400° F. which is far *below* its melting point, and while it is to all appearance solid—will have diffused to the top in notable quantities by the end of three days. Even if lead be heated only to 100° C. or 212° F., the diffusion of gold in it can be readily measured, notwithstanding that it is only 1–100,000th of what it is in fluid lead.

The diffusibility of one metal in another is a measurable property just like the electrical conductivity of a metal. The figures given in the last column of Table 10 are the number of grains of the diffusing metal which would pass in twenty-four hours through each square centimetre of cross section of the tube, if assays made at two points one centimetre apart along the tube showed a difference of one grain per cubic centimetre of alloy. The diffusibility is not directly indicated by the curves in Fig. 14, Plate 6, from which it can be obtained only by elaborate mathematical treatment. The curve marked platinum indicates a diffusibility of 1·69, and that marked gold a diffusibility of 3·1; while if complete diffusion took place, the distribution would be represented by the vertical line *bg*, and the corresponding figure of diffusibility in the table would be infinity. Thus the more nearly vertical the curve is, the greater is the diffusibility which is indicated thereby.

The practical bearing of this investigation is not remote, and may be sought in the following direction. It is admitted that the mode of action of an added element is one of the most important questions in metallurgy; and it is hoped that experiments on the diffusion of metals will go far to enable the problem to be solved. Many physicists hold what may be called the "gaseous theory" of metallic solutions, which supposes that, when the amount of the added element is very small in relation to the mass of metal in which it is hidden, the atoms of this foreign ingredient are so widely separated by dilution that they act with no more mutual restraint than would the atoms of a gas, and exert pressure in the same way as the latter. The rapidity with which diffusion appears to take place in very dilute solutions of molten metals lends material support to this gaseous theory of the action of an added element.

As regards the diffusion of solid metals in each other, it should be observed that the action of solids upon solids has long been known in industrial practice: the penetration of solid iron by carbon in the cementation process will at once occur to every steelmaker as a case in point, even though a gas may intervene in this process. The experiments summarized in the foregoing Table 10 constitute an attempt to measure the velocity with which metallic diffusion takes place. They have already led to the recognition of the undoubted fact, that it is possible actually to observe and measure the migration of the constituent atoms in a metal or alloy at the ordinary temperature; and as this points to unexpected possibilities of structural change in metals used in machinery and in engineering construction generally, it enforces the need for continuing the prosecution of the investigations which the Alloys Research Committee have still in progress.

Relation between Melting Points of Alloys and Atomic Volumes of their constituent Metals.—This is a subject to which brief reference was made in the third Report of the Committee (1895, page 251); and although the threshold of the enquiry can hardly even now be said to have been passed, it is desirable to indicate the nature of the information which the research reveals. Many years ago Raoul Pictet* showed that there is an intimate relation between the melting point of metals and the length of their molecular oscillations, namely that the length of oscillation at ordinary temperatures diminishes as the melting point rises; and it is known that the metals with the highest melting points are the most tenacious. He showed that this is the case with the well-known metals, and also that for all metals there is a simple relation between their atomic weight, the amplitude of the movement of their molecules under the influence of heat (that is, the coefficient of expansion), and their melting point. It follows, as stated in the last Report, that "the absolute temperature of the melting point of a metal must be closely connected with its *atomic volume*, because the former is inversely proportional to the rate at which the amplitude of the oscillations of the molecules increases with temperature; and the rate of increase of amplitude at any given temperature is obtained by multiplying the ordinary thermal coefficient of linear expansion by the cube root of the atomic volume." †

Since the last Report was presented, many alloys have been examined from this point of view, and the results are plotted in the curves in the diagram, Plate 8, in which tenacities and melting points are co-ordinates. It is not for a moment pretended that identity of condition has been attained in all the specimens examined; but the alloys as cast have all been made as strong as was found to be possible by carefully working the rods by hand under the hammer, and some approach to a standard condition has therefore been realised. Nearly all the rods were 6 inches long and 3–10ths of an inch diameter. The relation between the melting temperature and the tenacity appears to be much more definite in worked alloys than in the pure metals. This may be because an alloyed metal is in a more definite condition than one which is nominally pure. The alloy is less radically changed by traces of impurity than a metal is. Matthiessen* in his classical paper on the electrical conductivity of alloys (1860) pointed out that many metals probably undergo an allotropic change when another metal is added to them; and the addition of the first 5 or 10 per cent. of one metal to another usually sets up greater relative changes in its properties than do subsequent additions. The fact that metals are hardened both by alloying and by mechanical " work " suggests that in hammered alloys the metals would be in the most suitable condition for showing whether there is, or is not, a general connection between melting points and tenacities. Experiment proves that many alloys do fall on a curve AB, Plate 8, with melting point and tenacity as co-ordinates; and this strongly supports the view that there is such a connection. The pure metals have also been similarly plotted, and are found to lie generally on a different curve AD. For the latter curve the tensile strengths plotted have been gathered from various sources, which may partly account for the irregularity observed; and there appears moreover to be more difficulty in bringing pure metals than alloys to a standard condition; hence pure metals are quite unsuitable for accurate comparison. From Plate 8 however it will be seen that, considered in relation to their melting points, the pure metals are consistently weaker than alloys. When this question was brought before the Institution at the end of the last Report, one or two alloys had been tested, which proved to be much weaker than might have been anticipated from their melting points. These were at first thought to be anomalous; but closer examination showed that they really afford fresh insight into the influence of atomic volume on the strength of alloys. It was observed that all the alloys whose behaviour appeared to be exceptional were composed of two metals whose atomic volumes were identical or nearly so. Several other alloys of metals having nearly the same atomic volumes as each other were accordingly tested, and were all found to possess lower tenacities as compared with their melting points than alloys of metals having different atomic volumes. When the atomic volumes are identical or nearly so, the alloys appear to behave much as pure metals do; but as the identity of atomic volume of the constituents is never perfect, they cannot all be expected to fall on the curve AD. It should also be observed that true compounds of metals, which as is well known are mostly very brittle, do not fall on either line. Certain aluminium-gold or silver-cadmium alloys, or some of the brasses, present such examples; but this, as Fessenden has pointed out, is probably not because the union of the molecules of the compound is not strong, but is owing to the fact that in normal-sized test-pieces inability to yield leads to fracture, if the load is applied with the least divergence from uniformity; although, if the test-pieces could be produced as fine threads, they might be expected to possess great strength. Thus quartz is weak enough when tested in rods, but is strong in the form of quartz fibre as produced by Professor Boys. Steel is of such varied composition that it is difficult to say what would be a typical steel; but it is interesting to observe that the line AB in Plate 8 if produced would pass through a hardened steel having a melting point of 1,400° C. or 2,550° F. and a tenacity of 90 tons per square inch.

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* Comptes Rendus, vol. 88, 1879, pages 855 and 1315.

† Ibid., page 856.

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* Philosophical Transactions of the Royal Society, 1860, page 161.

The foregoing observations are offered tentatively. All the members of any one series of alloys do not admit of classification in connection with these curves, although the exceptions may usually be accounted for as being brittle "compounds." The general results as yet obtained appear however to be highly suggestive as affording a basis for a broad classification of alloys.

Improvements in the Recording Pyrometer.—In the last Report of this Committee a series of three curves were given (Proceedings 1895, Plate 39, Fig. 7) which at that time marked the latest stage of manipulation then attained. In those curves the freezing points of bismuth, of tin, and of standard gold containing one per cent. of bismuth, were successively recorded by a method fully described in that Report (page 244). The result afforded evidence that great delicacy in recording could readily be obtained; but the method was open to the objection that it involved a large angular deflection of the galvanometer mirror, whereby its suspending wires were severely strained; consecutive readings therefore could not be expected to correspond. It thus became a question to combine sensitiveness in the indications of the galvanometer with constancy of its zero. This was effected by the use of the following device. A galvanometer, specially constructed by Dr. Muirhead, was supported on a slate slab let into the wall in an underground vaulted chamber at the Mint, in order to ensure steadiness. The current produced by heating the thermo-junction attached to the galvanometer would deflect its mirror through a large angle, say 50°. This current from the thermo-junction however is never allowed to pass unchecked through the galvanometer. It is opposed by a current from a large Clark cell, the amount of which, by the aid of a specially constructed "potentiometer," could be readily adjusted and accurately measured, so that only a small portion of the current which would be generated by heating the thermo-junction really passes through the galvanometer. The general result is well exemplified in Fig. 17, Plate 9, in which the curve A B C D E is a faithful reproduction of the photographic record obtained for the freezing of tin. In this case the thermo-junction was really heated to the melting point of tin, 231° C. or 448° F.; but the galvanometer was deflected only a short distance from its zero line X Y, by a portion of the current corresponding at the point C to 27° C. or 49° F. The current produced by the remaining 204° C. or 399° F. was neutralized by the current from the Clark cell, and was measured by the potentiometer. The angular deflection of the mirror may therefore be quite small, even at the highest temperatures. It must not be supposed that the sensitiveness of the galvanometer is diminished; its resistance is not increased, but a portion of the current from the thermo-junction is balanced. The curve shows that in fact the galvanometer is highly sensitive; for the distance B C, which represents the surfusion of tin, is only 20° C. or 36° F. This delicate method of recording demands special arrangements for actuating the sensitized photographic plate which receives the record. The astronomical clock hitherto employed was therefore replaced by a water clock, consisting of a float moving upwards between guides, and bearing a photographic plate. The whole was enclosed in a light-tight case, provided with a horizontal slit, through which the ray of light from the galvanometer mirror has access to the plate. This plan is a convenient one, as it enables the chamber, which corresponds with the camera of the old recording instrument, to be illuminated without fear of "fogging" the plate. The progress of the spot of light along the slit can be observed by the operator, who, provided he does not obstruct the ray of light from the galvanometer, moves about freely in the chamber. In this system of recording it is absolutely necessary that he should be able to do so, because the electrical balancing has to be effected during the operation.

Comparison of the Thermo-junction with the Air Thermometer.—The question as to the degree of confidence which may be reposed in the numerical values of high temperatures is a most important one; and in connection with the last Report (Proceedings 1895, page 283) it was stated that the temperatures which had been accepted might be some 17° C. or 31° F. too low. Since that Report however, much work in this direction has been done. The determinations made by Professor Carl Barus,* who compared the air thermometer with thermo-junctions of different metals and alloys, are well known. More recently Holborn and Wien† have instituted a new investigation, and they also compared directly the air thermometer with the thermo-junction. Their experiments, which were very elaborate, were conducted with great care, and have done much to satisfy physicists as to the delicacy and trustworthiness of thermo-junctions. Still more recently Heycock and Neville, whose work has been so often referred to in these Reports, have re-determined a series of melting points by the aid of the resistance pyrometer, and their results give for the melting point of gold 1,061·7° C. or

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* United States Geological Survey, 1889, Bulletin No. 54.

† Annales de Chimie et de Physique, vols. 47 and 56, 1892 and 1895. Bulletin de la Société d'Encouragement, 1896, page 1012.

1,943° F., while Holborn and Wien give 1,072° C. or 1,962° F.; and Messrs. Holman, Lawrence, and Barr, assuming the temperature for the melting of pure gold to be 1,072° C. or 1,962° F., find that of copper to be 1,095° C. or 2,003° F., which is 13° C. or 23° F. higher than Holborn and Wien made it. Other results might be quoted as having been obtained severally by Violle, H. le Chatelier, Callendar, Erhard and Schertel, and by Barus. Results obtained by a new method of observation are also promised by M. Daniel Berthelot,* who in 1895 communicated to the Académie des Sciences the principle of a system of measuring high temperatures, based on the change which is produced by heat in the index of refraction of gases.

The general result of recent pyrometric work still leaves uncertain a range of some 10° C. or 18° F. in the melting point of gold, which is to be regretted, because this metal affords a highly convenient standard of reference. Differences of temperature however in the neighbourhood of 1,100° C. or 2,000° F. can be registered by the improved recording pyrometer with less error than one-tenth of a degree C. or one-fifth of a degree F. It therefore seemed well to employ the air thermometer in a series of new determinations of the melting point of gold. A number of preliminary experiments have already been made; and although the results cannot be completed in time for insertion in this Report, it may be well to describe the method which has been adopted. A porcelain bulb B, Fig. 18, Plate 9, having an internal capacity of 360 cubic centimetres or 22 cubic inches, is made of porcelain glazed externally, and is provided with a long tubular stem S, by which it is connected with a suitable apparatus for measuring the expansion of the air or gas contained in the bulb. A re-entrant tube R, closed at its inner end, affords the means of introducing a thermo-junction T into the centre of the bulb, though not of course directly into the air space of the bulb. The thermo-junction is supported by a suitable insulating tube. The receptacle consists of a clay chamber C, divided into two halves, which are held together by iron plates and bolts. The heating is effected by passing a current from a dynamo through the coils of iron wire I I, which are placed inside the clay chamber; and in order to ensure uniformity of temperature the clay chamber is made to revolve on axles A A. An inner shell of iron E is provided, in order to render the heating regular. The heat is steadily maintained for some time; and the readings of the thermo-junction and of the air thermometer are made simultaneously.

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* Comptes Rendus, vol. 120, 1895, page 831.

Some uncertainty as to what is the exact melting point of any given metal no doubt arises from the varying conditions under which different experimenters have worked. Thus while Heycock and Neville* find that copper melts at a temperature which is 19·8° C. or 35·6° F. higher than that at which gold melts, Holborn and Wien find a difference of only 10° C. or 18° F., the divergence being probably due to the presence of dissolved oxygen in the copper. Another cause of discrepancy between the observations of different experimenters arises from the fact that the temperature of a freezing mass of metal is not constant from the beginning to the end of the solidification. It seldom happens, for instance, that the freezing of a metal is represented in the cooling curve by an absolutely horizontal line; hence it is important to know whether the beginning or the end of the freezing has been noted; and it is evident that autographic records render it possible to state accurately what phase of the melting or freezing of a metal or alloy occurs at any particular temperature.

Conclusion.—It will be seen that the range covered by the work of the Committee during the past two years has been largely diversified; and the evidence thereby gathered, that there is constant and active molecular movement in solids, can hardly fail to be of importance in all industries in which metallic alloys are employed.

In concluding this Report I would offer my warm thanks to Mr. Alfred Stansfield and Mr. William H. Merrett, who have so ably assisted me in its preparation. The work of Mr. Merrett appears here for the first time, and he has proved himself to be a careful experimenter. To Mr. Stansfield, owing to the many claims upon my time, I have been obliged to entrust the entire conduct of certain portions of the research; and I knew that I could do so with confidence.

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* Chemical Society Journal, vol. 67, 1895, pages 160 and 1024.

Postscript.

In the curves of the copper-tin series of alloys, given as the result of Mr. Stansfield's experiments in Plates 41 to 43 of the Third Report (Proceedings 1895, page 269), the "freezing-point" curves in Plates 42 and 43 were incorrectly plotted from the "cooling" curves in Plate 41. There were also certain difficulties in the interpretation of the complicated series of freezing points which occur in the alloys containing from 58 to 80 per cent. of copper. It was therefore thought desirable to make a fresh examination of the copper-tin series; and the new results are given in Plate 10. This opportunity of reviewing the older work has also been taken advantage of for introducing the later determinations of the freezing point of copper (1,082° C. or 1,980° F.) and of tin (232° C. or 450° F.) The old results, corrected for these temperatures, are indicated by round dots crossed by a short horizontal or vertical stroke; and the two newer sets by crosses × and by circles. At the copper end of the diagram the curve traced through the initial freezing points of each alloy differs somewhat from the older result, and corresponds closely with the "complete freezing-point curve" published in March 1897 in an interesting paper* by Heycock and Neville. As there plotted, their results show the atomic percentages of tin in the several alloys; and they also give tabular statements of freezing points expressed in actual percentages of tin. As regards the subsidiary freezing points, which form so prominent a feature in Plate 10, they detect indications of eutectics at 793° C. and 745° C. and 228° C., or 1,469° F. and 1,373° F. and 442° F., which if plotted in Plate 10 would extend in a horizontal direction for a short distance from the main curve, that is, as far as the points marked *a* and *b* and *c* respectively. The search for such subsidiary freezing points however has evidently not been an object of their enquiry, which is mainly devoted to determining a complete series of initial freezing points of different series of alloys. From inspection of Plate 10 it is clear how complex are the changes which occur after the mass has become solid. As these subsidiary freezing points are what mainly influence the mechanical properties of the alloys and indicate their constitution, it is of the first importance that they should be determined and recorded.

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* Philosophical Transactions of the Royal Society, 1897, vol. 189 A, page 63.

The subject of the freezing of alloys is assuming considerable importance, and the nomenclature deserves careful consideration. There is some confusion between single cooling curves, taken in a few minutes by the autographic recorder, and curves drawn through the points afforded by a series of such curves. Such a series of points would represent weeks or months of work, and could be derived only from a series of curves obtained by the resistance pyrometer or by the thermo-junction pyrometer, either supplemented by the autographic recorder or depending upon direct observation. The designation "complete freezing-point curve," adopted by Heycock and Neville, will be gradually extended, it is to be hoped, so as to comprise all the subsidiary freezing points which can be detected in a given series of alloys after initial solidification has taken place.

As regards want of concordance between different sets of observations, it is hardly known yet to what extent initial freezing points are influenced by rapidity of cooling or by the presence or absence of surfusion. In the present series of alloys, cooling has been effected very slowly: the duration of cooling was more than an hour for each of the fifty alloys comprised in the new series.

The particularly interesting region which lies between 58 and 80 per cent. of copper, Plate 10, presents a curious series of eutectics connected by characteristic inclined lines. There is here seen to be a complete set of subsidiary freezing points occurring far below the main freezing-point curve, and presenting by themselves all the features of a complete set of freezing-point curves for two associated metals. Shortly I hope to publish a similar set which occurs in the copper-antimony series. It remains to be seen what a really complete plotting of the freezing points of the copper-tin or other complicated series will look like, when the alloys are subjected to rigorous scrutiny by the aid of more delicate appliances than those now in use.

Discussion.

Professor Roberts-Austen mentioned that, since the preparation of the present Report, a remarkable paper had been published by M. Henri le Chatelier in the *Revue Générale des Sciences* (15 Jan. 1896, page 11), in which the fullest appreciation was shown of the facts concerning what happened in alloys after they had become solid: which was the very point the Alloys Research Committee had so greatly desired should be made clear. It was an interesting circumstance, because the work embodied in the present Report differed from that of most previous experimenters in the fact that it dealt with metals and alloys after they had become solid, and not solely from the fusing point down to the solidifying point. There were naturally some omissions in the Report; and also at present a few inconsistencies, which might however be eliminated by further investigation. For instance, the influence of eutectics occurring low down in the cooling curve had been dwelt on as diminishing the strength of alloys; and yet in Plate 3 it was seen that amidst the strongest alloys there was a line *ee* marked "eutectic" as low down as about 460° C. or 860° F. It did not agree exactly with the group marked *e*EF: it was some 40° C. or 72° F. higher; and although the line indicating this eutectic as extending from 25 to 53 per cent. of zinc seemed as prominent in Plate 3 as that extending from 86 to 100 per cent. of zinc, yet it would be noticed that the corresponding low halting points in the cooling curves in Plate 2, from which Plate 3 was made up, were very slender indeed between 25 and 53 per cent. of zinc, whereas from 86 to 100 per cent. the low halts were strongly defined. This illustration would serve to show how complicated the question was.

(Professor Roberts-Austen.)

It was now being approached on the lines of the theory of solutions; and the constitution of solid solutions appeared to be so complicated that probably no one explanation would suffice by itself, and many might have to be attempted in order to account for the results obtained.

The curves shown in Plate 11 were the freezing-point curves of carburized iron, and served to show how this metal might be brought into line with ordinary solutions. These curves had been obtained quite independently in France by M. Osmond * so long ago as 1888, and recently by M. Henri le Chatelier, and in England by himself. At present he considered the diagram was hardly ready for publication, except in the most tentative way; and it was offered only because it suggested how certain differences of opinion that had arisen could be brought closely together, and their relations could be traced to the allotropy of iron, which was essential to the theory of the hardening of steel. [See page 90.]

In Plate 8, showing the relation between the tenacity and the melting temperatures of metals and alloys, he should have liked to add another curve showing the relation between the melting points of alloys and the atomic volumes of their constituent metals. The two curves shown in Plate 8 were merely given tentatively, and were by no means a complete representation of all the facts.

In page 36 of the Report reference was made to the necessity for the simultaneous use of the pyrometer and the microscope, before attempting to explain how structure was built up of molecules. The micro-structure of alloys he had fully hoped would have occupied a prominent place in the present Report; and Sir William Anderson and the other members of the Committee who had visited the Mint some weeks ago had seen the elaborate arrangements there made for conducting micro-photographic work with high magnification; these he had made under the guidance of M. Osmond, who might justly be called the greatest living student of the micro-photography of metals. The publication of any results however he was compelled to defer until a future meeting of the Institution. Hence it

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* Annales des Mines, vol. xiv. 1888, pages 39 and 59.

happened that, save for brief incidental references, micro-structure did not find a place in the present Report. This he the more regretted, because there was important work of other experimenters, with which he hoped on a future occasion to deal fully. Among the numerous workers in this direction were M. Behrens of Delft, and M. G. Guillemin of Paris, who some years ago had published several beautiful micro-photographic studies of the structure of copper and copper alloys; and in the report of the Société d'Encouragement, to which reference had been made, M. Charpy had systematically attacked the structure of the brasses, and had given no less than forty-eight admirable micro-photographs of them. Had the present Report dealt with microscopic work in connection with alloys, he should also have shown full appreciation of the researches of Professor Arnold, on whom, so far as Sheffield was concerned, the mantle of Dr. Sorby might be said to have fallen. In previous Reports it had been shown how the presence of a eutectic alloy fusible at a low temperature could be detected by the aid of the recording pyrometer, the eutectic being revealed by a halt low down on the cooling curve. In a paper published last year in "Engineering" (7th February 1896, page 176), Professor Arnold had shown that the presence of these low eutectics in gold and in copper might be revealed by the microscope, if the specimens had been subjected to certain thermal conditions which were carefully defined; and he hoped he would furnish an abstract of his results for the use of the Alloys Research Committee. Micro-photographic results he trusted would not be lost sight of in future work; but the investigation demanded a long apprenticeship, and he and his assistants had only recently attained the degree of proficiency therein which gave confidence to proceed to publication. For some time past however the micrographic apparatus had been devoted to the uses of the Mint; hence the absence of micro-sections from the present Report.

Sir WILLIAM ANDERSON, Past-President, desired, as Chairman of the Alloys Research Committee, and also in the name of the members generally, to tender to Professor Roberts-Austen and his skilful

(Sir William Anderson.)

assistants the heartiest thanks for this most valuable Report, the mere reading of which must have taxed to the utmost the attention of all present; they could therefore form a good idea of the amount of labour, pains, thought, and contrivance, which had been necessary in order to produce it. Those who had recently enjoyed the opportunity of visiting the Mint on Professor Roberts-Austen's kind invitation, and of seeing all the appliances he had prepared, would agree that the Institution had been most fortunate in being able to secure such a worker in this most important branch of metallurgy. Without adding anything to what had already been said on the theoretical aspect of the subject, he wished to make a few remarks on the practical results which in his opinion were to accrue from these investigations. All engineers knew how difficult it was to specify the composition of a metal such as would exactly meet their requirements. It was quite plain that the chemical method was impracticable, because they had learned from this Report, and from many other sources, that the presence of extremely small quantities of foreign matter, if it might be so called, had generally a very perceptible and sometimes even a serious effect; therefore a chemical examination, in order to be of any use, ought to be complete, embracing a search for every known element: which was of course altogether impracticable. This was not such a visionary difficulty as it might seem to be; for since the casting of gun-steel had been given up at the Royal Arsenal, it had become necessary to keep in store a large quantity of steel ingots, out of which at short notice guns or parts of guns could be forged. The mechanical test for a cast ingot was manifestly impossible, and therefore reliance had been placed up to the present on chemical tests alone; and for these it was only possible to specify the proportion of ingredients usually found in steel. But there was a great financial risk connected with the method adopted, because some of the ingots were not used for weeks or months or even years from the time when they were supplied; and therefore if, when required, they should turn out to be unsuitable, the nation would have to bear the loss. It had long appeared to him that by the use of cooling curves the chemical investigation might be supplemented, and irregularities due to the presence of unsuspected foreign substances might be revealed. It had indeed been for practical use in this manner that the first recording pyrometer had been designed for him by Professor Roberts-Austen, but used temporarily, as he thought, at the Mint for the Alloys Research Committee. His own intention had been to have it transferred to the gun factories at the Arsenal, as soon as Professor Roberts-Austen had done using it; but he was glad to think that that day was yet far distant, and he should be compelled to ask him to design another apparatus to be used at the Arsenal, for the purpose for which the one that had done such good service had been originally intended.

The same considerations applied to another important branch of the work at the Arsenal—a branch which during the last few years had extended rapidly—namely the manufacture of brass powder-cases for quick-firing guns. He exhibited a specimen of a disc of brass, $12\frac{5}{8}$ inches diameter by $\frac{3}{4}$ inch thick and weighing $28\frac{3}{4}$ lbs., shown one quarter full size in Figs. 21 and 22, Plate 12; and also of a cartridge-case for a 6-inch quick-firing gun, 16 inches long and tapering from 7 inches diameter at the breech end to $6\frac{1}{2}$ inches at the muzzle end, shown one quarter full size in Figs. 37 and 38, Plate 16, which had been formed out of the disc by successive squeezings, drawings, pressings, and annealings, until at last the metal had been tortured out of the flat disc into the long thin case exhibited, and the only tool-work upon it was the turning of the extracting ring or flange and the trueing up of the base; the rest was just as the case came out of the last die, the weight when finished being $22\frac{1}{2}$ lbs.* These cases were now made in large

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* The following is the complete series of operations, the chief of which are illustrated one quarter full size in Plates 12 to 16. (1) Punching out of sheet metal the blanks or discs shown in Figs. 21 and 22, Plate 12. (2) Forming a cup out of the disc in a hydraulic press, Fig. 23. (3) Annealing and cleaning. (4) First draw, Fig. 24; in this and the rest of the eight successive draws the base of the cup is forced foremost through the die by a loosely fitting internal plug or plunger, and so draws the cylindrical shell after it. (5) Annealing and cleaning. (6) Second draw, Fig. 25, Plate 13. (7) Annealing and cleaning. (8) Third draw, Fig. 26. (9) Annealing and cleaning. (10) Fourth draw,

(Sir William Anderson.)

numbers, and they were precisely similar in form and in mode of manufacture to the smaller solid-drawn cases of the magazine rifle, of which latter as many as two millions had sometimes been made in a week. The proportion of the metals in the brass was 70 per cent. of copper and 30 per cent. of zinc. Experience had shown that this was the best proportion in which the two metals could be alloyed for this purpose. On looking at the curves given in Plate 3, it would be seen that this proportion corresponded closely with the maximum extensibility as determined by Charpy and by Thurston, and with the maximum amount of work done in extension, that is, the product of the stress multiplied by the maximum extension. It also came near the point B on the freezing-point curve, where the first eutectic alloy separated out. What appeared to him to follow from these correspondences was the hope that one great difficulty in drawing up a specification would be avoided. It was not desirable to specify the purest copper, because he was not sure that the purest copper would be the best for the purpose; and the same could be said of the zinc. What had at present to be done was to say that the only copper which would suit for these cartridge-cases was the Lake Superior copper, or the American electrically deposited copper, or the Burra Burra or the Wallaroo, those being the only kinds that would make

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Fig. 27. (11) First indent of the base or head, Fig. 28. (12) Annealing and cleaning. (13) Fifth draw, Fig. 29. (14) Annealing and cleaning. (15) Sixth draw, Fig. 30, Plate 14. (16) Annealing and cleaning. (17) Seventh draw, Fig. 31; followed by (18) first trimming of mouth to dotted line, and (19) drilling air hole in head, Fig. 31. (20) Second indent of head, Fig. 32, Plate 15. (21) Annealing and cleaning; this is the final annealing. (22) Eighth draw, followed by (23) second trimming of mouth to dotted line, Fig. 33. (24) Heading, or forming the external flange on the base or rear end, Fig. 34, Plate 16; followed by (25) rough turning the head down to Fig. 35, and (26) coning the mouth inwards, as shown in Fig. 36. (27) First tapering of the cylindrical shell, and (28) second tapering; each is effected by pushing the case mouth foremost into a tapered die. (29) Finishing the turning of the head, Figs. 37 and 38, Plate 16; boring and finishing the primer hole; boring the mouth, and finishing it to length; and (30) notching the rim of the mouth, Fig. 37. The weight when finished is 22½ lbs. (31) Stamping mark on head; filing; cleaning; gauging and examining. (32) Lacquering.

cartridge-cases satisfactorily. The same thing applied to the zinc, which must be either Vieille Montagne, or one or two other brands. This he considered was by no means a satisfactory way of framing a specification, because the copper and zinc were not produced in this country; they were in the hands of merchants, and therefore the purchasers were obliged to take for granted what the merchants told them in selling these materials. The only test was whether the materials would make what was required; and this was a most expensive test to apply, because it involved so large a quantity of work, of which a great deal might have to be thrown away, and the regularity of production might be seriously interfered with. It seemed to him that there was now great hope that specimen ingots could be made out of the materials supplied, and by means of the recording pyrometer it might be determined in an hour or two whereabouts the eutectic point B occurred in the freezing-point curve; and when this indication was combined with a mechanical test, the two together would give the precise information required, and the material might be bought with safety and with economy in consequence of a possible widening of the market. Not only so, but he thought it was further possible that, if the copper and zinc were of such qualities that for the usual alloy the eutectic point B moved either up or down, the materials might still be rendered perfectly suitable by simply varying slightly their relative proportions so as to meet the shift of the eutectic point. If this could be done, he could only say that at the Royal Arsenal, at any rate, it would be nothing less than a discovery of the greatest possible practical value, tending to great economy and certainty in obtaining these costly materials.

Looking at the specimens exhibited, would anyone imagine it possible that a material which had stood being tormented out of a plain flat plate into a long cylindrical cartridge-case was capable of splitting through the base spontaneously? Yet such was the fact. Instances had occurred in which some of these cartridge-cases, made in Birmingham, out of material which must have been of first-rate quality because the cases could not have been made at all out of anything else, had cracked through the base in the Arsenal stores.

The effort of the material to recover itself and to return to its normal internal state had been sufficient to cause its rupture. At first this had been thought due to sudden changes of temperature; and the makers of the cases had tried to persuade the Admiralty to put up heating apparatus in the stores, so as to maintain them at a constant temperature, and also to keep each cartridge-case in a flannel bag, which seemed hardly a practical plan for a warlike store. But the cartridge-cases made in the laboratory at the Arsenal never behaved in that way. On comparing the method of manufacture in the two places, it was found that at the Arsenal the work was done more gradually: there were a larger number of operations, more drawings, and more annealings, whereby the internal stresses arising from so extraordinary a flow of metal were obliterated at a greater number of stages, and in the end a cartridge-case was produced which did not crack spontaneously.

Sir William H. White, Member of Council, was sure he spoke the sentiments of the members in saying that this Report was one which, when it came to be studied, would have a wide bearing on their work in all departments of engineering. It would also have a practical influence in various ways on the manufacture of alloys. In the manufacture of armour-plates the effect of alloys and the diffusion of metals entered in a highly practical way; and some of the recent advances that had been made, there could be no doubt, were the consequence of great attention having been given both to the alloys of metals and also to the modes of treatment. Without going further into detail, he should like to express on his own behalf and on behalf of the members of the Institution their great obligation to Professor Roberts-Austen and to those who had worked with him, for having attacked these problems in a manner which combined the highest scientific research with the clearest perception of what was of great practical value. The present Report, forming one of a series of which the Institution might well be proud, would no doubt in future be quoted as a classic, and would lead to still further investigation, both in this country and abroad. The handsome acknowledgment which Professor Roberts-Austen had made of the work of other investigators, and especially of Professor Arnold at Sheffield, struck the true note of progress, showing the warmest recognition by an original worker of the researches prosecuted by others. This was the spirit in which all scientific and industrial work should be undertaken.

Mr. J. E. STEAD had read Professor Roberts-Austen's successive Reports with the deepest interest and pleasure; and the great value of the work done by him had induced himself to make other experiments for promoting the better knowledge of alloys. Referring to the eutectic alloy of lead and tin (pages 43 and 47), it was a remarkable fact that for generations all tinmen had used that particular proportion of the two metals in order to make the most fusible solder for their work. In watching such workmen it would frequently be found that they did not trouble about weighing the lead and the tin, but simply kept on adding tin to the lead in the ladle and pouring out a little of the mixture on a slab, until at last they obtained metal which set with a perfectly bright surface, and then they knew that they had the most fusible solder. It so happened that the most fusible solder was the identical eutectic alloy shown in Plate 4, freezing at B and containing about 32 per cent. of lead and 68 per cent. of tin. In the sample exhibited it would be observed that it was not perfectly bright all over its surface; there was a little white spot in the centre of the small tablet of solder, which indicated that it was not quite a perfect alloy, although it contained exactly the 32 per cent. of lead indicated in Plate 4; the little white spot showed that there was a slight deviation from the true proportion necessary to make a perfect alloy. On adding only 1 per cent. more of lead, the white spot increased in size; with an addition of 2 per cent. it got larger still, and with an addition of 3 per cent. of lead the tablet was white all over its surface. On the other hand, going down the scale and reducing the proportion of lead by 1 per cent., again the white spot increased; and going down still further, the white spot still continued to increase. This was an exact confirmation of what had been noticed by Professor Roberts-Austen, that, in cooling, one part of an alloy

(Mr. J. E. Stead.)

crystallized after another part. When solidifying, the eutectic behaved like either of its constituents, when they were separately allowed to solidify: it had one solidifying point, the surfaces of small cakes remaining bright. The moment however that the proportion was increased of either one constituent or the other, it began to form a compound which crystallized before the eutectic alloy; and the result was that a mass of crystals was formed on the surface of the cooling alloy; then the more fusible alloy in contracting sank down, leaving the crystals in beautiful relief. The frosted appearance on the tablets of solder exhibited was nothing more nor less than crystals of the higher melting compound on the surface of the eutectic alloy; and it was this peculiar appearance that had been used as a guide by plumbers for generations in making their solder.

Alloys of lead and antimony, upon which he had also been working, had a close relation to those of lead and tin, as well as to those of various other metals, so that a description of one set of alloys would to some extent hold good for all: only the successive compounds crystallized out in different ways and in a characteristic manner. With an alloy of lead and antimony containing 15 per cent. of antimony he had found that the solid mass slowly cooled had on the top a little cream-like layer, of very small thickness in comparison with that of the whole mass. By increasing the amount of antimony to 20 per cent. the cream was increased in thickness; and with 30 and 40 per cent. it became still thicker and thicker, until when 50 per cent. of antimony was reached the whole of the alloy seemed to the naked eye to be a homogeneous creamy mass. When examined microscopically it was found not to be homogeneous, but to consist really of innumerable white patches of what appeared to be little cubes of pure antimony. In order to ascertain whether it was pure antimony or not, he had carefully separated them by the action of weak nitric acid, and on analysis had found them to contain only 0·2 per cent. of lead; and they had a specific gravity of 6·5, approximating to that of pure antimony, which was 6·71. He exhibited photographs of the actual pieces of these several alloys in their natural size, as they appeared after simply polishing on emery paper and then etching with a little acid.

Another important question touched upon in the Report was whether the eutectic alloys were of a constant chemical composition or not (page 41). When dealing with perfectly pure metals he believed it would be found that all eutectic alloys were of a definite chemical composition, either simple or complex. In the series of alloys he had examined of lead and antimony, he had found that, after cutting off the creamy top, the remainder, which constituted the eutectic alloy, had the exact chemical composition Pb_4 Sb, which was a compound of lead containing 12·7 per cent. of antimony, the equivalents or atomic weights of lead and antimony being 207 and 120 respectively. Moreover this eutectic compound had a perfect crystallization of its own: further evidence that it had really a definite chemical constitution. The crystals of antimony were cubes, whereas the crystals of its eutectic alloy with lead were hexagonal, and were so excessively fine that it was only by magnifying them under a microscope with a high power that the beautiful little crystals could be detected. The various compounds of lead and antimony showed cooling curves so nearly identical with the lead-tin cooling curves that one series might almost be substituted for the other, after altering the temperatures. Contrary to the statement of almost every English text-book, he had found that the melting point of antimony was not 440° C. or 824° F., but 630° C. or 1,166° F. The specific gravity of antimony was 6·71, while its eutectic alloy with lead had a specific gravity of about 10½; the result was that, the moment the cubes of antimony crystallized in the cooling mass, up they floated and formed the beautiful creamy layer at the top. This circumstance had a practical bearing. In working with antimony alloys it was important to cast at a temperature as low as possible, and into cold moulds so as to aid rapid solidification; the result then was that, instead of getting the antimony separated from the eutectic alloy, it was fairly distributed throughout the mass. A similar thing occurred with alloys of tin and antimony. Adding 10 per cent. of antimony to the tin, under ordinary conditions of casting the whole etched surface was observed to be covered with beautiful little cubes of a hard bright substance. As the proportion of antimony in the tin was increased, these cubes continued to increase, until at 30 per cent. they became the preponderating feature. On separating these hard cubical crystals by dissolving out the eutectic alloy, they were found to consist of one of those compounds which would have been called by Guthrie a chemical "metalo-metallic salt," or Sb Sn. The eutectic alloy had a melting point of about 250° C. or 480° F., and this critical point was present in all the alloys containing between 7 and 50 per cent. of antimony. When about 45 per cent. was reached, a new form of crystallization was obtained, which he had no doubt would be found to have another critical point, when Professor Roberts-Austen came to examine it. He had himself not got quite so far yet as to be able to speak more decidedly upon this matter. The interesting point was that in this series the difference in specific gravity between the eutectic alloy and the cubical crystals of what might be called tin antimonide was not so great as between the lead-antimony eutectic and the separated antimony in lead alloys of antimony. Consequently, with ordinary care in casting, the crystals as they formed did not rise to the surface; but if the cooling was done very slowly, the little cubes were found at the top in the same way as in lead alloys of antimony. The crystals of Sb Sn he believed had here been isolated for the first time. The presence of the hard bright cubes had been noticed in Britannia metal by Professor Behrens; but there was no evidence that they had been separated by him. An interesting point about them was that, if after separation they were melted under cyanide of potassium, they split up into a compound which crystallized in plates, and a eutectic melting at 250° C. or 480° F.

Professor J. O. Arnold expressed his warm thanks to Professor Roberts-Austen for his kind reference to the work done at the Sheffield School, where new lines of research had already been started upon in connection with many of the suggestions which were embodied in the series of Reports presented to the Alloys Research Committee. In connection with the eutectic alloys one or two practical points had arisen, which it might be of interest to mention. If to pure molten gold were added Professor Roberts-Austen's standard quantity of 0·2 per cent. of bismuth, it was found that the metal solidified in irregular grains of pure gold; but round each individual grain, separating it from all its neighbours, was the eutectic alloy; and the result was that the mass, as so frequently pointed out by Professor Roberts-Austen, was almost as brittle as a piece of chalk. If a piece of the same gold, the size of a pea, were heated to a temperature far below red heat, the eutectic alloy surrounding the grains became quite pasty; and the piece of gold could be powdered in a mortar into small grains, the eutectic alloy breaking away from the grains of pure gold. After powdering the piece of gold in that way, he had selected two small granules of equal size, and had himself flattened one slightly and found it had none of the brittleness of the original mass; and the other he had sent without comment to a gold-beater, by whom it had easily been beaten out into a piece of gold leaf without showing any sign of fragility.

A matter of practical importance to which attention might be called in connection with the alloys research was the difference in the influence of arsenic and of phosphorus upon iron. Having experimented on alloys of nearly pure iron with 1½ per cent. of phosphorus, and of nearly pure iron with 1½ per cent. of arsenic, he had found that the arsenic alloy could be bent double while cold, whereas the phosphorus alloy was as brittle as glass. Unfortunately engineers had got hold of the idea that arsenic was almost as injurious to steel as phosphorus, in spite of the able researches of Mr. Stead, who had carried out a large series of experiments on this subject on a practical scale. The result of that erroneous belief was really serious in the large steel-works, for they were at the present time hampered by not being allowed more than 0·02 per cent. of arsenic in the steel made. It had been clearly shown by Mr. Stead that the mechanical effect of 0·1 per cent. of arsenic upon mild steel could not be gauged. Large steelmakers had got their pig-iron pure and all their other ingredients in the proportions required, and as far as they knew their ores of the right quality; but it was difficult to get a fairly representative analysis of a large parcel of ore, as it varied considerably all through the parcel. The consequence was that in steel made from the same materials the arsenic might be got down to 0·02 per cent. or even a little lower, but suddenly, two or three heats afterwards, the percentage would jump up to 0·05, arsenic being introduced from the ore into the steel. The result was that the steel was useless for the specification for which it was prepared, although even the 0·05 per cent. would do very little harm. The reason was because the percentage of arsenic varied in the ore, in which occurred aggregates of some arsenical compounds that had perhaps not been met with in the main analysis. If the Alloys Research Committee could see their way to take up and definitely settle the question of the influence of arsenic upon mild steel, so that existing requirements could be modified in that respect, he thought they would be conferring the greatest benefit upon the steelmakers of Sheffield and of the country generally.

Mr. WILLIAM GOWLAND, as a member of the Alloys Research Committee, had much pleasure in echoing Sir William Anderson's remark that the Institution should be heartily congratulated on having such an able and original worker as Professor Roberts-Austen to conduct this research into the nature and properties of alloys. The present Report he considered was of the highest value, not only by reason of its purely scientific results, but also on account of their practical bearing upon the manufacture of alloys in industrial works. M. Charpy's determinations of the actual temperatures at which the annealing of brass was effected (page 38) would be of considerable value to all engaged in the working of brass. It was known to all manufacturers of brass and other alloys that their own workmen employed at the annealing furnaces had not missed the fact that a low temperature was all that was necessary for satisfactory annealing. In ordinary brass-works, where generally the annealing furnaces were too few in number, the men could not anneal as they would like; but whenever any casting had to be annealed which had afterwards to be dealt with by severe hammering or rolling, then they gave the metal what they called a "soaking," that is, they kept the casting for a considerable time at a much lower temperature than was usual in the ordinary annealing.

The collocation in Plate 3 of the curve representing the freezing points of the copper-zinc alloys with those representing their tenacity and extensibility seemed to him to be of such value that he thought a recording pyrometer ought to be introduced into the laboratory of every metallurgical works, where he was sure that it would give satisfactory results. Whenever castings were met with which rather failed in rolling or hammering, or were destitute of the tensile strength they ought to have, he believed if such failures were investigated by means of the recording pyrometer a flood of light would be thrown upon their causes. At present the causes of the failures which so often occurred were extremely obscure and often inexplicable; and here he believed the recording pyrometer would give valuable aid.

Another matter of great importance, which had been brought out by the curves in Plate 3, was that the strongest alloy of the copper-zinc series, namely the alloy which contained 60 per cent. of copper and 40 per cent. of zinc, had practically only one freezing point. If the same should be found to be true of other metals and other alloys, then in endeavouring to make binary alloys with other metals it would only be necessary to aim, if a strong alloy were wanted, at getting an alloy which had only one freezing point, and such an alloy might almost confidently be expected to prove the strongest of the series. The tensile strength of nearly 27 tons per square inch, shown by the curve AR T in Plate 3 for the brass containing 60 per cent. of copper, was even less than what he had himself generally obtained in the Imperial Mint, Japan. There he had worked generally with castings of a much larger size, and had dealt with them by severe rolling. If the alloy containing 60 per cent. of copper was made with Japanese copper or any other good copper, and with spelter containing not more than from 1·6 to 1·7 per cent. of lead, he had found there was no difficulty whatever in getting a rolled bar having a tensile strength of from 38 to 42 tons per square inch: in which case the apex of the curve AR T would be shifted a little to the left; and he noticed there was a cross mark a little to the left of the curve, which would seem to justify shifting it as he suggested.

(**Mr.** William Gowland.)

With regard to the influence of eutectics on certain properties of alloys (page 48), it was well known by all who were concerned in manufacturing brass and similar alloys, what a wonderful effect the addition of a small quantity of iron with a small quantity of tin had upon the strength of a metal allied in composition to Muntz metal, and that their effect was altogether out of proportion to the quantities of these additions. According to Table 9 (page 49) the tenacity of the brass when cold was increased in Professor Roberts-Austen's experiments from 20 tons up to 25 tons per square inch. This he thought was even understating the increase; for, having himself made a considerable number of experiments with similar alloys, he had found that an alloy similar to that given in Table 9, but containing only about 1·3 per cent. of iron with a little more tin than the quantity stated in the analysis, would have regularly a tenacity of from 30 to 34 tons per square inch. The way in which these small quantities of iron and tin together acted in order to produce so high a tenacity had been quite inexplicable, until now satisfactorily explained in the present Report, in which it was shown that the weakness of the copper-zinc alloy was due solely to the low eutectic freezing point; and when this was removed by the small additions of iron and tin, the tenacity was increased. This he thought was one of the most valuable practical points that had come out in the present Report; and it appeared to him to be extremely probable that, if this was true of the effect of small quantities of iron and tin on these copper-zinc alloys, the same would be true of the influence of small quantities of other metals on other alloys, which would be a highly important fact in a metallurgical laboratory. In dealing, for instance, with a binary alloy which was found to have a low freezing point, it would be recognised that the latter was due to a fusible eutectic; and all that would have to be done would be to add a small quantity of some other metal to the alloy in order to render the eutectic less fusible, with the certainty of thereby increasing the strength of the alloy. Not only was a wide field here opened for experimenting upon metallurgical alloys, but experimenters were shown the actual lines on which it would be best to proceed: namely to aim at getting rid of the break low down in the cooling curve, which could be done by diminishing the fusibility of the eutectic by a small addition of another metal. Many years ago he had been engaged in a long series of experiments on the copper-zinc alloy, namely ordinary yellow brass, containing 70 per cent. of copper and 30 per cent. of zinc; and his aim had been to obtain a triple alloy which should have a greater strength than the copper-zinc alloy. After making a great many alloys in which the zinc was gradually replaced by tin, he had found that the strength was hardly increased materially. Had the method of examining alloys by means of their cooling curves been known to him then, he should have discovered at once that he was working in the wrong direction, because he should have found that the additions of tin were not removing the low break in the cooling curve; in fact in some instances they were possibly lowering it. Such knowledge would have prevented probably about two or three months of fruitless experiments.

The action of bismuth on gold, which had been described by Professor Arnold (page 81), was exactly the same as the action of bismuth on silver, which he had himself described previously in his remarks on the Second Report (Proceedings 1893, page 175). At the time when he was in charge of the Imperial Mint, Japan, and was able to deal with large quantities of the precious metals, he had found that by the addition of a little bismuth the ingots of silver were rendered extremely brittle; if merely dropped on the ground they broke into two or three pieces. The ingots themselves consisted of a mass of crystals, each of which was perfectly ductile, while the ingot as a whole was so brittle. The cooling curves accompanying the Report in 1893 showed that the reason for the brittleness of the ingot was the presence of a fusible eutectic, which surrounded each of the crystals.

The application of the method of testing by means of cooling curves to the purposes mentioned by Sir William Anderson (page 75) was no doubt most desirable, although there might naturally be great difficulties in arranging for carrying it out in practice. Chemical analysis was highly valuable, but it did not tell all that was wanted to be known. Again if copper, for instance, were tested by its electric conductivity, it was true that any best-selected copper which would give from 98 to 100 per cent. conductivity according to Matthiessen's standard would always give good results in an alloy; but if this condition were fixed upon as the limit for accepting copper for brass work, the effect would be to condemn a large number of other qualities of copper which would act quite as well as those having such high conductivities, and indeed many would act even better. Electrotype copper had also been mentioned by Sir William Anderson (page 74) as only one of the best kinds of copper to use for making brass for the manufacture of such cartridge-cases as the specimen exhibited. This conclusion was entirely confirmed by his own experiments with electrotype copper and also with best-selected copper; in many instances he had found that best-selected copper which contained no antimony and a mere trace of arsenic would surpass some kinds of electrotype copper for making a brass that was to be so severely worked as these cartridge-cases. In this connection there was also a highly important matter in which the cooling curve and the freezing-point curve might prove of great value. All copper which was intended for such use as was illustrated by these cartridge-cases should contain the smallest possible proportion of cuprous oxide, that is, it ought to be cast at the highest tough pitch; because if it contained any considerable quantity of cuprous oxide, the latter immediately acted upon the zinc added for making the brass, and produced a highly infusible oxide of zinc, which was more or less diffused through the brass and certainly impaired its strength. The recording pyrometer he thought should be able, after the brass had been made, to show whether there was present more than a certain proportion of the infusible oxide of zinc.

Again, the recording pyrometer he thought would be of great value indeed in the examination of spelter. It was unfortunate that at many metallurgical works, where great pains were taken with the examination of copper, the spelter was neglected. Spelter contained large quantities of impurities: rarely less than 0·8 per cent. of lead, and generally 1½ per cent. or more. Although this did not affect the properties of the brass, yet some of what were called the pure re-distilled spelters, which had been introduced lately, contained from 3 to 6 per cent. of cadmium. The melting point of cadmium was different from that of zinc; and a recording pyrometer he thought would at once be able to detect by a break in the cooling curve whether zinc contained an injurious proportion of cadmium or not. On some alloys he should say that cadmium had an injurious effect.

Dr. **DAVID WATSON**, Manager of the works of the Broughton Copper Co., Manchester, wrote to express his high appreciation of the value of this most stimulating and welcome addition to metallurgical literature, and of the way in which the results recorded in the present Report were compared with the work of others and elucidated thereby, and were applied to the explanation of the difficulties and occurrences that were every day met with. Having a good deal to do with the manufacture and working of copper-zinc alloys, the portion of the Report dealing with these was of special interest to himself. The part played by iron in some of these alloys was important, more particularly in the large group of special alloys containing 60 per cent. of copper; many of these were employed under fanciful names, and great skill was shown in their manufacture. The small additions by which their tensile strength was increased were of iron, aluminium, manganese, and tin, in proportions up to 2 per cent., either one metal alone by itself, or two or three together, and either with or without addition of phosphorus. The general effect aimed at was to increase the tenacity, with an improvement in the elastic limit and more or less diminution of the elongation. The following figures would serve to illustrate the effect of a small addition of iron, and of iron and phosphorus, to an alloy containing 70 per cent. of copper and 30 per cent. of zinc; the samples tested had been thoroughly worked and afterwards annealed before testing:—

	Tenacity per sq. inch.	Elongation.
Brass containing 70 per cent. of copper and 30 per cent. of zinc, without addition . .	20·2 tons	65½ per cent.
Same Brass, with addition of 0·5 per cent. of iron	24·2 tons	31¼ per cent.
Same Brass, with addition of 0·5 per cent. of iron and 0·1 per cent. of phosphorus . . .	26·5 tons	28 per cent.

(Dr. David Watson.)

These results of old experiments he had looked up in connection with the experiments upon brass and upon Aich's metal in the present Report. From what he knew of the subject he thought the explanation offered upon this point in page 48 hardly quite met the facts which were relied upon by the manufacturers of these special alloys: such as the effect of the small addition of phosphorus in the above instance.

Professor ROBERTS-AUSTEN explained that a small addition of phosphorus removed the oxygen in the alloy, and in that way brought up the tensile strength. The example just referred to and that dealt with in the Report were therefore widely different in this respect.

Mr. F. W. HARBORD, Royal Indian Engineering College, had frequently had to examine brass tubes for locomotive boilers, for which experience had shown that the best alloy was that containing about 70 per cent. of copper and 30 per cent. of zinc. This practically corresponded with the alloy which possessed the best mechanical properties, as deduced from the curves shown in Plate 3. One of the most interesting and most important points in the Report was the comparison of brass with Aich metal made by the addition of 1½ per cent. of iron to the brass alloy. It was here clearly shown that an alloy with a low fusible eutectic was weak, and one with a high fusible eutectic was stronger. In steel, which was the substance he was more especially interested in, it was known that phosphorus did form a highly fluid phosphide of iron; and it might be that the latter was itself a low fusible eutectic, which would account for the great brittleness of phosphoric iron. Arsenic he agreed with Professor Arnold (page 81) was not nearly so injurious to steel as phosphorus, the effect of arsenic not being at all marked until 0·2 per cent. was reached in mild steel. Having himself repeated the whole of Mr. Stead's experiments on steel, and also the analyses, he could confirm the results independently. But it should be borne in mind by engineers that those experiments were all on low-carbon steels; high-carbon steels had yet to be dealt with, and he hoped Mr. Stead had this matter in hand. In any steel however he believed that up to 0·1 per cent. of arsenic there was nothing to fear; and this assurance practically met any doubts of the steelmakers, for in this country, as far as he knew, no steel was made which contained more than about 0·06 per cent. of arsenic. Possibly the more marked injurious effect of phosphorus on steel, as compared with arsenic, might be explained by the phosphorus forming a more fusible eutectic alloy than the arsenic, as would seem probable from theoretical considerations; and this would be a most interesting point to investigate.

In the curves accompanying the present Report he should like to ask to what extent small traces of impurities could be observed. Ordinary commercial brass, for instance, contained from 0·3 to 0·8 per cent. of lead and bismuth; could the effect of such small impurities as these be noticed in the curves? The great value of the Report to himself was its suggestiveness: it would indeed require a lengthened course of work to carry out all the experiments and suggestions here indicated.

Mr. ALFRED STANSFIELD, referring to the utility of the recording pyrometer in the investigation of the industrial brasses, and its value in exposing the low eutectic *ee*, Plate 2, which occurred in their cooling curves, pointed out that, in considering in what way the pyrometer might be employed by brassfounders for studying the properties of these brasses, the difficulty presented itself that, if a specimen of brass had to be melted up in order to take a cooling curve from it as it solidified again, it would be quite possible that its composition might be changed during the melting. Such a mishap might of course be guarded against to a certain extent; but it seemed to him that, without actually melting the brass at all, highly valuable information might be obtained by simply taking a piece of the solid brass, drilling a hole in it, and putting a thermo-junction into it, heating it up to a certain temperature short of the melting point, and then cooling it down and taking an autographic curve during the cooling. No doubt if the conditions were studied, and all the experiments were conducted in a similar way, differences could thereby be detected, which for a general report like the present it had not been attempted to find out.

(Mr. Alfred Stansfield.)

Solid solutions, to which reference had been made in pages 36 and 52, formed a subject which would no doubt come with increasing prominence before the Alloys Research Committee. Without attempting to define solid solutions precisely, their general nature could be realised from observing that, when a solution of salt in water froze, the ice which first formed was purer than ordinary salt water. Was that ice quite pure? or did it contain a little salt? If it contained a little salt, then it was a solid solution. In the same way in the lead-tin alloys, if, in the cooling of an alloy rich in lead, the metal which first crystallized out was not quite pure lead, then it must be a solid solution of tin in lead; and this was important, because, if in the freezing of an alloy containing but little tin the latter formed a solid solution, it might be possible that there might not be any eutectic alloy present, and that all the tin might remain in the solid lead as a solid solution, and might not form any eutectic alloy. This had been shown by M. Osmond and Professor Roberts-Austen to be the case in certain gold alloys; and the investigation he hoped would be extended in the future. After roughing out the general cooling curves, it would then be necessary to investigate the smaller changes which took place during solidification. These solid solutions were of course extremely important in the iron-carbon alloys, such as steel. In Fig. 20, Plate 11, were shown, as already mentioned by Professor Roberts-Austen (page 70), the ordinary freezing-point curves of carburized irons, in which the horizontal distances represented the percentages of carbon in the iron, and the vertical scale represented the temperatures at which the halts indicated by the spots occurred in the cooling curves of the several members of the carbon-iron series. The part G S P of the curve indicated the halts which occurred in the cooling of solid pieces of pure iron and of steel; these points had been investigated by a large number of observers, and had been plotted by Sauveur * to form a curve. The halts plotted in Plate 11 had been obtained by actually melting the carburized iron, and taking

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* Transactions of the American Institution of Mining Engineers, September 1896.

cooling curves in the ordinary way. It was found that the cast-irons had, like any ordinary series of alloys, a eutectic line *a c*, with curves BA and BD sloping up from the point B. In the cooling of an alloy containing say 3 per cent. of carbon, the excess of iron began to crystallize out at 1,220° C. or 2,230° F., and the eutectic solidified at 1,120° C. or 2,050° F., while the carbon recalescence point occurred at about 680° C. or 1,260 F., as seen in Plate 11. The percentage of carbon in the eutectic alloy would depend a good deal on the presence or absence of other substances. In this series the eutectic contained about 4·3 per cent. of carbon, an alloy of this composition showing only a single freezing point B at 1,120° C. or 2,050° F., besides the recalescence point at about 680° C. or 1,260° F. If more carbon were added, which could conveniently be effected by the aid of the electric furnace, a double freezing point would again be noticed, as at 4·5 and at 5·5 per cent. of carbon; now however the upper point of the two indicated the separation of graphite. It would also be seen that the line PP′ was analogous to the line *a c*; it was a eutectic line, not indeed a liquid eutectic, but what might be called a solid eutectic, that is, the eutectic of a solid solution. Solid iron at temperatures above 650° C. or 1,200° F. contained a certain amount of dissolved carbon; in a steel containing 1·25 per cent. of carbon the excess of carbon began in cooling to crystallize at 850° C. or 1,560° F. as cementite, as shown by the point marked in the line SE, and the rest of the carbon was thrown out of solution at about 670° C. or 1,240° F. In a steel containing 0·6 per cent. of carbon the iron was in excess, and it separated out at 700° C. or 1,290° F. as ferrite; then the carbon separated from the rest of the iron at 650° C. or 1,200° F. The line MO, representing the intermediate point of recalescence Ar2 in low-carbon steels (Proceedings 1893, page 155), would appear to denote another solid eutectic; but further evidence was required to establish this inference. If the curve BA was followed up, it led from the eutectic B of the carbon-iron alloys up to the melting point A of pure iron; while similarly, if the curve SG was followed up, it led from the eutectic point S of the solid solution up to the point G in pure iron, which since the iron was solid must be called a

(Mr. Alfred Stansfield.)

point of allotropic change. Hence the allotropic-change point G in iron was related to the solid solution of carbon in iron in the same way that the melting point of iron was related to the liquid iron-carbon solution. The above was a mere outline of the information afforded by the curve; but it would be evident that no explanation of the recalescence of steel could be complete, which did not take into account the allotropic change of iron.

Dr. T. K. ROSE, Royal Mint, thought one of the most interesting inferences from the present Report was that, the more alloys were investigated, the more did it appear that chemical compounds seemed to become less and less important, and that solutions, solidified or liquid, seemed to become more and more important. It might occasionally happen that originally a compound might for a time be supposed to exist; but it had also happened that the assumptions on which such a supposition had been based had soon been shown to be ill-founded. Not long ago M. Charpy had expressed the belief that he had established the existence of the compound Cu_2 Zn, containing about 66 per cent. of copper. It appeared possible however from Plate 3, that there was no such compound, because the diagram and Table 8 showed at least two freezing points for an alloy of that composition; and it seemed certain that a true chemical compound if pure could have only one.

With regard to the eutectics, he supposed there was no doubt that, where there was a eutectic freezing at a low temperature, the alloy in which it was developed must be weak. But it seemed almost equally certain that the low eutectic must be developed, before it could be a cause of weakness. For example, in that part of the copper-zinc curve which comprised all the strongest brasses, it was seen in Plate 3 that nevertheless a eutectic was sketched out low down at *ee*. Now it seemed to him probable that all these strong copper-zinc alloys were exactly on the same footing as the Aich metal, from which a similar eutectic was caused to disappear by adding another metal. In the strong brasses he had no doubt this low eutectic was caused to disappear by mechanical treatment of one kind or another. The eutectic if it was latent could do no harm; in order to have an injurious effect it must be developed. It had been suggested by Mr. Stansfield (page 89) that much could be found out by heating up the solid metal or alloy to above the eutectic melting point but below the melting point of the whole mass. In one instance only, he thought, had this been done yet; and the results seemed to him to be in the highest degree promising. Last year the alloy containing 70 per cent. of copper and 30 per cent. of zinc had been heated by M. Charpy up to between 500° and 600° C., or between 900° and 1100° F., and had been kept at that temperature for a long time; and it had then been found that the tensile strength had fallen off by nearly one-half, but that, if the same piece was afterwards re-heated to almost any temperature below the melting point of the mass, no further falling off took place in the tensile strength. It was therefore evident that by the long-continued heating the eutectic, which had before been latent, had been fully developed; and no doubt this was mainly the cause of the falling off in the tensile strength. The existence of this eutectic melting at about 470° C. or 880° F. had been quite unknown to M. Charpy; and it was not until its subsequent discovery by Professor Roberts-Austen that the real meaning of M. Charpy's experiment could be perceived. The difference in the behaviour of pure and of commercial copper, when heated in the annealing furnace for a long time, afforded another instance of the effect of a developed eutectic.

The PRESIDENT was glad to announce that Professor Roberts-Austen would prepare a supplement to the present Report for discussion at a future meeting. Meanwhile he was sure the members were all unanimous in their appreciation of the value of this fourth Report to the Alloys Research Committee. No doubt many would desire to have experiments and reports upon other metals, such as iron and steel, which perhaps were more important to themselves individually than those already treated of. But patience must be exercised; and in the meantime it would seem that the reports were all leading up to those two metals, with which indeed he believed Professor Roberts-Austen purposed dealing if

(The President.)

possible in the fifth Report. Pending its presentation, to which he was sure all were looking forward with the greatest interest, he would now ask the members to offer to Professor Roberts-Austen and his assistants their best thanks for the most valuable Report which had just been presented, and to express their high appreciation of the work already accomplished.

Mr. ROBERT A. HADFIELD, as a member of the Alloys Research Committee, wrote that he considered the Institution was to be congratulated upon this excellent fourth Report of Professor Roberts-Austen; the admirable summary here presented of past and recent work would prove of great service to all interested in this important subject. With the remarks in page 33, regarding the importance of even what used to be looked upon as no more than "traces" of elements in alloys or compounds, especially in steel, he was himself strongly in agreement. It was Professor Roberts-Austen's observations upon his papers on manganese-steel, read before the Institution of Civil Engineers in 1888 (vol. xciii, page 88), which had largely led to his closer consideration of this matter. As previously pointed out, the reputation of Sheffield for high-class steel was chiefly based upon a recognition of the fact that for some purposes so small a variation as only two-hundredths of one per cent. in some of the metalloids present in steel might make the difference between a good and a bad product. Hence it could be seen how important it was, when determining the qualities of any alloys or combinations, to know the extent to which, for example, sulphur and phosphorus were present, even to the minutest of differences.

As to the elements which went to produce steel, the statement of Dr. Étard, quoted in page 33, hardly held good; for thus far no other element but carbon had been found to convert iron into steel, that is, into true steel which would harden. Having himself made many hundreds of alloy experiments during the last ten or twelve years, he had always found that a decreasing percentage of carbon was attended with decreasing hardness, and the further away from true steel did the product recede. Howsoever the combinations might be arranged, the result was always in this direction.

The law of atomic volume, useful as it might be in some respects, could hardly be called a law to metallurgists, or at any rate to those concerned in iron and steel manufacture, if anomalies of serious character were found. Regardless indeed of iron, the effect of arsenic, an element of large atomic volume, upon copper, a metal of much smaller atomic volume, was not to render the alloy soft and brittle, but, as had been so clearly pointed out by Professor Roberts-Austen in previous reports, to toughen and strengthen the product considerably. The general statement in page 35 should therefore, he thought, be somewhat qualified. The more this complex question of alloys was studied, the more was it found that a set of alloys, giving apparently most concurrent results up to a certain point and leading to but one conclusion, became entirely modified from the theoretical point of view by one or two exceptions. Too often did the occurrence of "the little rift within the lute" prevent even the best surmises from entirely supplying that complete and satisfactory explanation which all were striving to find.

The portion of the Report devoted to the diffusion of metals was not only of great interest, but of the highest practical importance. If the makers of alloys of all kinds would only remember the remark in page 56, that the rate of diffusion was greatly increased by a small rise in temperature, there would be less faulty and imperfect work with alloys, and less would be heard about segregation as such.

The statement on page 62, that "the foregoing observations are offered tentatively," was one which all interested in this work would do well to bear in mind. There was still far too much to be done before it could be said of alloys or combinations that all the reasons respecting them were known; and in the light of the present still imperfect knowledge it was only tentative explanations that could be offered.

At the Sheffield Technical School he might mention that Professor Arnold had been carrying out an excellent and important series of investigations upon copper alloys, the Committee of the School being wisely of opinion that work of this kind in regard to these alloys, as well as to those of iron and steel, should prove of great practical importance.

M. OSMOND wrote complimenting Professor Roberts-Austen upon the excellent manner in which he was conducting the work of the Alloys Research Committee. It was now evident that cooling curves afforded the necessary basis for investigating any group of alloys, and that these curves should be continued down to the ordinary temperature. By this means a first idea was obtained of the points of interest to be studied in the group. The use of the Le Chatelier pyrometer, in conjunction with the autographic recorder devised by the author, was admirably adapted for such investigations. After the number and position of the critical points had once been accurately determined, it was next necessary to ascertain by the aid of chemistry, physics, and micrography, what was the exact meaning of each point; and then what part each played in the processes of manufacture, and in the mechanical properties of the finished material. This was the only methodical mode of procedure. In default of such a method, useful data might chance to be met with, but they would remain disconnected, and would often allow the best way of solving practical difficulties to be missed. Probably many experimenters would be dismayed at the complexity of the phenomena to be met with in studying a group of alloys. But when the general laws were once established, the investigation of details became relatively easy. It was none the less true that, in order to keep up with the development of practical work at the present time, adequate preparation was needed, such as was not everywhere available.

Professor ROBERTS-AUSTEN said that in the present Report his endeavour had been to cover the whole ground of the numerous subjects dealt with, rather than to investigate fully the details of particular points. The whole aim of the Report had thus been to be largely suggestive rather than exclusively practical. No one who understood the kind of work which had here been done would look upon it as of an unpractical description; and his own strongest wish throughout the whole conduct of this research had been to show that there was absolutely no difference in reality between science and practice. If manufacturers of bronze or brass or any other alloys would now examine afresh their own special work in the light which he ventured to hope had been thrown upon it, and would investigate it with the aid of an autographic pyrometer, he thought they would find that their investigations, if recorded as he trusted they would be, would develop into reports of considerably greater length than the one which had just been presented. He was much gratified by the appreciation evinced by the various speakers of the work already accomplished.

It would be easy to take curves in the Royal Arsenal of the kind advocated by Sir William Anderson (page 75), which would afford a basis for indicating whether the alloys did or did not possess the mechanical properties desired, and were or were not suited for the work demanded from them.

Of steel, which had to be employed by Sir William White on such a magnificent scale in naval construction and for armour plates (page 76), the true constitution was only beginning to be understood; but even in relation to steel it was evident that the presence of eutectic alloys was of vital importance.

The observations offered by Mr. Stead (page 77) were of so much interest that it was to be wished he had directly discussed the copper-zinc alloys which formed a main feature of the present Report. It was true that, if perfectly pure metals were dealt with, it would be found that all eutectic alloys were of a definite chemical *composition* (page 79). But it must be remembered that, as stated in page 41, there were theoretical reasons for supposing that a eutectic alloy could not possibly be a chemical *compound*. As the most fusible alloy of a series, a eutectic could not be a chemical compound; because, if it were, it would be possible to produce a still more fusible alloy by a further addition of one of the constituent metals. The bearing of crystallization upon this question demanded further investigation.

As to the error in the text books respecting the melting point of antimony, he quite agreed with Mr. Stead (page 79) in fixing the melting point at 630° C. or 1,166° F.; this was the temperature he had himself determined from a commercial sample. In 1895 it had been found by Messrs. Heycock and Neville to be 629·6° C. or

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1,165·3° F.; and in July last M. Gautier * had given it as 632° C. or 1,169·6° F.

It was gratifying to be reminded by Mr. Gowland (page 85) that it was a cooling curve given in the Second Report in 1893 which had led him to detect the presence of a fusible eutectic of bismuth and silver, surrounding the crystals of silver in the ingots intended for coinage. The great metallurgical experience of Mr. Gowland rendered his appreciative remarks specially valuable. The remarks of Dr. Watson (page 87) were also highly interesting.

The action of arsenic on carburized iron, which had been referred to by Professor Arnold (page 81), had been touched upon by Mr. Harbord (page 88), who probably knew all that was at present known in relation to this subject. The extent to which small traces of impurities could be observed by means of the cooling curves would depend upon the degree of delicacy given to the recording instrument. A minute quantity of impurity could be detected by a change in the direction of the cooling curve, even if the impurity were not present in sufficient quantity to produce a halt or break in the curve. The only difficulty was to ensure that a particular portion of the cooling curve, which contained the possible eutectic, should be made to fall within the limits of the sensitized plate, because the latter could not conveniently be made more than a foot square. If it happened that the impurity was present in very small quantity, it would probably not form a eutectic, but would remain as a solid solution in the metal; and its presence would be manifested only by a lowering of the initial freezing point of the metal, and possibly by a change in the form of that point.

A specific piece of work had been undertaken by Dr. Rose (page 92), which had originated in the research conducted for the Committee; and his attention would doubtless be directed experimentally to the interesting points he had raised.

With respect to the opinion expressed by Mr. Hadfield (page 94) in regard to steel—that thus far no other element but carbon had

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* Comptes Rendus, vol. 123, 1896, page 112.

been found to convert iron into true steel which would harden—it had always been held by M. Osmond and himself that the relations of carbon to iron presented certain peculiarities, especially as regarded the carbon change which occurred at the lowest point of recalescence Ar1 (Proceedings 1893, page 155). These peculiarities were moreover related to the allotropic changes in iron. If the definition of steel were based, as it here appeared to be, solely on a peculiarity due to carbon, then it was clear that carbon-steel was the only steel. In these Reports however the word steel had been used in a far more general sense. Starting from the fact that an element like nickel, or hydrogen in electro-iron, augmented the hardness of iron even though quenching were not resorted to, he concluded that the element behaved in a similar way to carbon, and possessed "hardening power." This was indeed an incontestable fact; and any objection to such a conclusion rested only on the meaning to be attached to words. The considerations respecting the different groups of steel—nickel-steel, manganese-steel, carbon-steel, and other varieties—had been clearly and beautifully treated in M. Osmond's contribution to the discussion upon Mr. Sauveur's American paper, which he hoped would soon be published.

As regarded the law of atomic volume (page 95), it was only reasonable to ask that it should be applied to the cases it was intended to meet, namely to solid solutions. The objection that the behaviour of arsenic was not in accordance with this law must be met by the consideration that, if the foreign element formed, as arsenic did, a definite compound with the metal to which it was added, the molecular volume of the compound was clearly not that of the free element; and instead of a solid solution a mechanical mixture might be formed, so that the influence of atomic volume might no longer be dominant. Even in true solid solutions there were other factors than atomic volume to be considered, such as the presence of gas and the nature of the joints formed during the cooling of the mass. In complex problems in which many factors were called into play, it was the very essence of the experimenter's art to separate the factors, and to consider them in

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succession, in order that the effects of many variables might not be confused. The necessity for stating these cases over again arose from their seeming not to have been understood.

Molecular change might be produced by mechanical stress. Alloys of silver and cadmium had been described recently by Gautier; and some of the alloys of this silver-cadmium series, which under certain conditions were white, had been found by himself to be distinctly coloured when they were subjected to longitudinal stress in a testing machine, even under conditions which prevented the test piece from being heated by the process. It would be interesting to know whether Heycock and Neville had found that a similar colour effect, due to molecular change, was produced by stress in the silver-zinc series of alloys, on which they had recently made some beautiful experiments. Such evidences of molecular change would he thought be of interest to Mr. Hadfield, as the alloys did not contain carbon.

PARTIALLY IMMERSED SCREW-PROPELLERS FOR CANAL BOATS; AND THE INFLUENCE OF SECTION OF WATERWAY.

By Mr. HENRY BARCROFT, of Newry.

The discussion which followed the reading of the author's former paper on "Twin Screw-Propellers with Adjustable Immersion, fitted on Canal Boats," at the Manchester Meeting of this Institution in 1894 (Proceedings, page 360), seemed to indicate that a somewhat fuller consideration of the principles involved in the action of these Partially Immersed Screw-Propellers might be of interest to the Members, in connection with the experience resulting from his further experiments on this subject, and from his observations on the influence of Section of Waterway upon the progress of Canal Boats.

Action of Screw-Propeller.—In all screws, considered apart from friction, two efforts—propulsive and rotary—are dividing their share of the power between them in unequal proportions: so much so that in an even-pitched screw, where the angle varies over the whole radial length of the blade, the loss due to the effort of rotation becomes very great over that part of the blade which is inclined at an angle of more than 45° to the beam of the vessel. When this angle is exceeded, in all probability the power absorbed by rotation is even greater than that expended in forward or propulsive effect. Applying this reasoning to the blades of the partially immersed propellers employed by the author, which are so made that no part of their surface exceeds this angle of 45°, it is submitted that a greater percentage of efficiency is obtained, as represented by the ratio of thrust to rotary resistance, than with an ordinary screw, in which a considerable area of blade near the boss has an inclination greater than half a right angle.

In all ordinary screws therefore the effort of rotation absorbs a great amount of power. Moreover the lower half of the propeller moves laterally against a greater head of water than the upper portion during rotation; it consequently meets with greater resistance each time a blade passes the bottom centre. This the writer thinks cannot fail to have a lateral effect on the ship. If proof were needed, it is afforded by the fact that, with the ordinary single central screw, the ship's head would turn to the right if the screw revolved in its upper half to the left, and *vice versâ*, unless the helm were kept over at an angle sufficient to counteract the lateral influence. It is said that steamers have lately been built, including the "Umbria" and "Etruria" of the Cunard line, with the main shaft some inches out of the centre, on the side opposite to that towards which the screw revolves in its upper half; and that in these vessels the helm is carried more nearly amidships for going right ahead.

In the case of the partially immersed propellers, where the upper half is out of the water, their steering influence is much greater, although up to a certain speed no loss of power in addition takes place; and in order to neutralise the lateral effect of each singly, and to carry a midship helm, the twin propellers being right and left handed, it is necessary in a boat of 60 feet length and 15 feet beam to place the propellers about 34 inches out of the centre, instead of only about 18 inches as is assumed in the case of the wholly submerged screw. This explains the seeming anomaly of a propeller, placed so far from the centre line of the boat, having no influence on the steering, as is found to be the case when only one of the partially immersed twin-screws is in action. In a recent experiment with the lighter "Agnes," one of the twin propellers was taken off and left behind on the quay; and it was found that the vessel propelled by the other, which was 34 inches out of centre, made a perfectly straight course, the tiller being left free without a hand upon it: thereby proving that each propeller, when out of centre to that extent, is in itself absolutely neutral as regards steering.

Size of Screw.—The foregoing considerations will also help to explain the desirability of having a screw in this instance of large diameter in proportion to the boat. By means of large diameter the advantage can be gained of a slow speed of revolution, and at the same time a small angle of blade suffices to give the desired pitch. The large diameter also enables the large blade to be stopped or cut-off as soon as the angle reaches 45°, while yet retaining blade surface enough for operating on a sufficient body of water to minimise the slip, which is so excessive in a small screw of high velocity when driving a slow and heavy boat. The advantage claimed for the large diameter is illustrated by the use of snow-shoes, which enable a man to walk on snow with only ordinary exertion; whereas with common boots his feet would sink at every step, and the labour of walking would thereby be greatly increased. Another illustration is afforded by the use of wheels with broad rims for moving heavy loads on soft ground; with sufficiently broad wheels one horse would do as much work on soft ground as two harnessed to a wagon having wheels no broader on the rim than those of a brougham. This reasoning would not apply to ordinary steamers, where the screw blade area is proportioned to the mass and velocity of the boat; but in a canal the water is usually so shallow that a screw must necessarily be of comparatively small diameter if wholly submerged. The large screw has the additional advantage of not causing any wash; and thus propellers can be employed in cases where canal banks are soft and easily damaged.

Section of Waterway.—A vessel moving freely in open water may have an average amount of slip; but should she enter upon a confined section of water her progress becomes slower, notwithstanding that the propellers may be making almost as many revolutions. The retarding influence increases as the section of the water diminishes, until the way of the vessel may be completely stopped, and she may even commence to go astern instead of ahead, while the propellers are still continuing to revolve in the same direction for forward progression. Here the difference between the progress and the pitch multiplied by revolutions cannot be described as slip, unless the meaning of the word is much more extended than that entertained by most nautical authorities.

If a ship were passing through solid matter in the manner of a plough, the displacement of the ship would be apparent by the vacant space left behind. In a confined waterway however, as the ship proceeds, the water in front passes astern, and so at slow speeds no vacancy or even depression can be noticed. If it were necessary to demonstrate this, it can be done by putting a float on the water with a sinker attached, and, when a boat passes a confined section, observing the speed at which the float and sinker pass an object on shore on their way sternwards. It will be found that, in proportion as the section of waterway is smaller, the speed of the float will increase. This experiment, which can be tested any day when a barge is moving in a narrow canal, proves the existence of an induced current sternwards as the boat proceeds. In this current the barge floats, and is carried with it in a backward direction, just as she would be if stemming or ascending the current of a river, or if moving against the tide in an estuary. In order therefore to understand the decline in progress of a boat when in a narrow waterway, it is necessary to realise that this current of displacement is passing sternwards, and that, as the boat floats in the current, she must be subject to its influence, and must be carried aft bodily at its velocity. Her progress through the water may remain as in open water, or nearly so; but her progress over the ground will be no more than her open-water progress minus the velocity of the induced backward current. The apparent slip in this case is, firstly slip as it occurred before entering the narrow section, and secondly the velocity of the displacement current, which will vary in proportion to the difference between the cross section of the boat and the cross section of the waterway. In most cases also a further decline of speed results from the diminished rate of revolution of the screw. These considerations show how impossible it would be to obtain high velocity in a narrow channel with a large boat, no matter how effective might be the mode of traction or propulsion; and no more can be done than to diminish by suitably proportioned propellers the losses of every kind when in open water, so that on entering narrow sections no more loss may be sustained than the direct and inevitable loss resulting from the induced sternward current.

It may thus be seen that slip as generally understood may be but little increased by contracted cross section of waterway, although the apparent slip may be great, owing to the vessel being carried backward in her own displacement current. It is only in narrow channels that this current is strong and unmistakable; but it is a question at what proportion of cross section of vessel and cross section of waterway it practically ceases. So far from ceasing altogether, is it not possible indeed that it may exist even in open water, and thus may occasion part of the loss usually attributed to the thrust of the screw acting on a yielding substance and driving water astern? It is true that next to the skin of the ship there is a thin frictional current set up, travelling with the vessel; but like the vessel itself it is within the greater current outside, and must be carried bodily sternwards with the motion of the water in which it is contained.

On some shallow canals ordinary screws have lately been introduced; and it is not uncommon to find that, when the pitch multiplied by the revolutions gives say ten miles per hour, the speed of the boat when towing is only three miles per hour, and with the displacement current added a speed of not more than four or four and a half miles per hour is accounted for. The velocity of the displacement current cannot at present be estimated with exactness, so far as the writer knows, for it varies so much with the sectional form of the canal; but a sufficiently near approximation can usually be made. The question of most consequence in the present connection is, what becomes of the power represented by the difference between the ten miles per hour of the screw and the four to four and a half miles per hour made up by adding together the speed of the boat and its displacement current? Part of the loss, and perhaps a considerable part, may be accounted for by the violent rush of water which shoots away from the screw, the loss from this cause being in a certain proportion to the velocity of the current. But even if the screw could be expanded on entering the narrow section, so that the water in its wake should travel aft no faster than previously, there would still be a loss which would increase with the diminution of water section. This loss may be explained as follows. The displacement current passing sternward can derive its motion only from the influence of gravity: that is to say, a head of water must be created in front of the boat by the propelling power, and the velocity of the current sternward will vary with the head which may be so created. Thus the sources of loss of power, or of seeming disappearance of power, are twofold:—the creation of a head of water in front of the vessel; and the friction produced by the sternward current which is kept in motion by this head.

The new partially immersed propellers are of such large diameter and area in proportion to the power that under similar circumstances the thrust wave following the boat is practically nil, because the abutment of water acted upon is so large that it refuses to move away backwards, and the power is exerted almost wholly in pushing the boat forward. This is the explanation of the observed fact that no preceptible wash or wave from the thrust current can be detected on the bank when the adjustable twin propellers are at work. It also explains the observed fact that the horse-power developed by the engine is almost wholly accounted for by the sum of the speed of the displacement current added to the speed of the boat. Finally it explains why—with the twin screws of large area and partially immersed, whereby the surface portion of the water is chiefly acted upon—no depression of the stern takes place, and consequently no loss of carrying power arises from this cause; because in most canals the boats carry as much as the depth of water will permit, and if a drop of six inches had to be allowed for, it would mean many tons less than if no such allowance had to be made. Independently the captain of a steam barge with ordinary screw on an English canal found that the stern sank as much as five inches when plying with a full load in shallow water. On another English canal the screw steamers when towing cannot carry more than about 22 tons, while the barges they tow, of the same size and build, carry 40 tons; allowing 9 to 11 tons for machinery and coal, the reduction of carrying power by depression of the stern would appear to be from 7 to 9 tons. On the contrary the "Newry" with her large propellers partially immersed has passed through the Newry Canal when drawing one inch more than the draught permitted and more than horse boats passing through on the same day; the excess of draught was an accidental occurrence, owing to her having started from Belfast for her trip before the water level had fallen in the canal.

The influence of section of waterway is illustrated by the following analysis in Table 1 of No. 10 voyage of the "Ulster" in October 1893 through the Newry Canal from Newry to beyond Portadown, a distance of approximately 37,460 yards or 21·3 miles, with a cargo of 34 tons. Her draught forward was 4 ft. 4 ins., aft 4 ft. 5 ins., and immersed section 46 square feet. Her propellers of 4 ft. 10 ins. diameter and about 5 feet pitch were immersed 3 feet deep, from the surface of the water down to the bottom of their circumference. Each of the fourteen stages given in Table 1 has practically a different sectional area. From the time occupied in each successive stage has been calculated the time that would have been spent on the whole journey of say twenty miles, provided the speed had throughout been the same as in the several stages. The sectional area of the water in the canal at Moyallen, between locks 13 and 14, was 180 square feet, giving a ratio of 3 of water to 1 of boat; and here the speed attained was 2 miles an hour. At Carumeen, between locks 5 and 6, with closely the same nominal water section, a deduction of 40 square feet must be made for the water being at the time 1 foot below the ordinary level, as was the case also in some other stages; and 23 square feet must also be deducted for weeds, leaving a net section of 119 square feet, and a consequent ratio of only 1½ of water to 1 of boat. Here the speed fell to only one mile an hour. It is difficult to be exact in the measurement of the water sections, because in some cases the obstruction is chiefly weeds at the sides of the canal, the middle being tolerably clear. With the large twin propellers, as the proportion between the cross section of canal and the cross section

TABLE 1.—*No.* 10 *voyage of Steam Lighter "Ulster" in Newry Canal, October* 1893.

Stage; numbers and names of Locks.		Time.	Distance.	Speed.		Time for 20 Miles.	Propellers.	
				Per Minute.	Per Hour.		Revolutions per minute.	Loss of effect.
No. Name of Lock.	No.	Minutes.	Yards.	Yards.	Miles.	Hours.	Revs.	Per cent.
3, Bishop's Lock, .	to 4	21	1210	57½	1·96	10		
4, McGurgan's, .	to 5	14	770	55	1·87	10¾		
5, McKnight's, .	to 6	58	1833	31½	1·08	18½	46	61
6, Dickson's, . .	to 7	55	1540	28	0·95	21	46	68
7, Goragh, . .	to 8	60	2420	40½	1·37	14½		
8, Ainsley's, . .	to 9	50	3080	61½	2·10	9½		
9, Gordon's, . .	to 10	40	2200	55	1·87	10¾		
10, Hall's, . .	to 11	23	1255	54½	1·86	10¾		
11, Poyntzpass, .	to 12	132	6270	47½	1·62	12⅓	48	44
12, Hunter's, . .	to 13	52	2530	48½	1·66	12		
13, Madden, . .	to 14	98	5332	54½	1·85	10¾	49	37
14 to Whitecoat (river) .	.	37	1760	47½	1·62	12½		
Whitecoat to Portadown .	.	23	1980	86	2·93	6¾	52	6
Portadown to Pottery .	.	55	5280	96	3·27	6	58	4

of boat declines, the speed of the propellers declines also. The explanation suggested of this is that the frictional resistance offered to the displacement current by the slopes of the banks constitutes a load upon the engine, having the same effect as increased cargo; and that, in making up the sum of the work done, there should be added to the speed of the boat and the speed of the displacement current a quantity, at present unknown, representing the creation of head and the friction of the displacement current. This would vary of course with the shape of the section of channel: the greater the wetted surface in proportion to the section, the greater would be the drag upon the boat.

A study of the following Table 2 (pages 110–111), compiled from data obtained in the passage of the steam lighter "Tyrone," Plate 21, through the Newry Canal, will show how largely the progress of a boat is influenced by contracted section of waterway. Those details lead to the surmise that it would be perfectly practicable to construct a table, by means of which the progress of a boat under given conditions of waterway could be approximately calculated beforehand. In making the observations for Table 2, ten sections of the canal were taken, as shown in Figs. 1 to 10, Plates 17 to 20; but in five of them the weeds were so long and thick that these five have been omitted. The observations recorded in the last two columns were taken eight days after the others, when the water level had in the meantime lowered four inches; except this, and the fact that the propellers were depressed three inches lower in the water, the only difference was in the supply of steam to the engine. On 8th May the link handle was in the second notch, and on 16th May in the first notch, so that in the last two columns all the steam possible was pouring into the cylinders; the effect of the increased immersion of the propellers and the greater area of water acted upon, combined with the increased quantity of steam, resulted in reducing the slip from 15 and 18 yards per minute in the same sections of the canal to 8 and 11 yards respectively.

The experience gained since the former paper in 1894 enables the writer to reply more fully to the objection then raised, that when

TABLE 2 (*continued on opposite page*).

Voyage of Steam Lighter "Tyrone" in Newry Canal, May 1895.

Lighter 60 feet length, 14½ feet beam, 4 ft. 10 ins. draught. Cargo 65 tons.
Two Screws 4 ft. 10 ins. diameter, 5 ft. 3 ins. pitch;
three blades, each 576 sq. ins. area.

a	Number of observation		1
b	Date	1895	May 8
c	Section of Canal	*See Sections Figs.* 1 *to* 10, *Plates* 17 *to* 20	Fig. 9
d	Immersion of Screws		3 feet
e	Canal, width of surface	feet	52
f	„ wetted perimeter	feet	56½
g	„ sectional area	square feet	256·9
h	Lighter, sectional area submerged	square feet	64·8
i	Water, sectional area remaining	square feet	192·1
j	Ratio of Water to Boat		2·96 to 1
k	Progress of Boat over ground	yards per minute miles per hour	90 3·06
l	Displacement Current, from line j	yards per minute miles per hour	30 1·03
m	Progress of Boat through water, lines $k + l$	yards per minute miles per hour	120 4·09
n	Revolutions of Screws	per minute	72
o	Revolutions × Pitch of Screws	yards per minute miles per hour	126 4·30
p	Slip, line o − line m	yards per minute miles per hour	6 0·21
q	Steam Pressure, per square inch above atm.	lbs.	100
r	Indicated Horse-Power, approximate	I.H.P.	15·6
s	Hours for 20 miles, from line k	hours	6·5
t	H.P. hours for 20 miles, line r × line s	H.P hours	101

(*concluded from opposite page*) TABLE 2.

Voyage of Steam Lighter "Tyrone" in Newry Canal, May 1895.

Two Cylinders 4½ inches diameter and 7 inches stroke.
Revolutions of engines 3¼ to 1 of propellers.
Water level in canal 4 inches lower in Nos. 7 and 8 on 16th May.

2	3	5	6	7	8	*a*
May 8	May 8	May 8	May 8	May 16	May 16	*b*
Fig. 1	Fig. 2	Fig. 3	Fig. 7	Fig. 1	Fig. 2	*c*
3 feet	3 feet	3 feet	3 feet	3 ft. 3 ins.	3 ft. 3 ins.	*d*
40	40	33	30	40	40	*e*
46½	45½	40	35½	46	45	*f*
239·2	224·8	150·8	127·5	229·2	214·2	*g*
64·8	64·8	64·8	64·8	64·8	64·8	*h*
174·4	160·0	86·0	62·7	164·4	149·4	*i*
2·69 to 1	2·46 to 1	1·32 to 1	0·96 to 1	2·39 to 1	2·31 to 1	*j*
71 2·42	64 2·18	45 1·53	34 1·15	80 2·72	71 2·42	*k*
26 0·88	26 0·88	34 1·16	35 1·20	31 1·05	30 1·02	*l*
97 3·30	90 3·06	79 2·69	69 2·35	111 3·77	101 3·44	*m*
64	62	58	58	68	64	*n*
112 3·82	108 3·68	101 3·44	101 3·44	119 4·06	112 3·82	*o*
15 0·52	18 0·62	22 0·75	32 1·09	8 0·29	11 0·38	*p*
100	95	95	95	100	100	*q*
13·6	12·6	11·0	11·0	17·6	16·8	*r*
8·2	9·1	13·0	17·4	7·3	8·2	*s*
111	114	143	191	128	137	*t*

propellers work partly out of the water a serious loss of efficiency immediately takes place, caused by air being drawn down by the blades. In the literature of screw propulsion this has become an axiom, which however the writer finds himself unable to accept unconditionally. That a loss takes place is true; but the explanation is questionable that it is caused by air being drawn down. In a recent valuable paper on economy and speed in connection with ocean voyages Mr. John Inglis suggested the consideration of an imaginary vessel, which could be altered at pleasure in any or all of her dimensions. Similarly with an imaginary propeller, which could at pleasure be enlarged or contracted in diameter, if by its revolving with the tips of the blades out of the water its efficiency were impaired to the extent say of 15 per cent., the loss could be restored by simply increasing the diameter of the propeller so as to act on a greater number of square feet of water per minute. The cause of the previous loss of efficiency was not that air was drawn down, but that during a portion of the revolution each blade emerged from the water and ceased momentarily to act as a propeller. Propulsion depends on the work done during the time the blades are submerged; and, if the screw was properly proportioned for complete immersion, it will cease to have sufficient area when the tips of the blades emerge from the water. The speed of revolution will then increase at the same time that the speed of progress of the vessel will gradually diminish. The action of the blades will be to churn the water; and instead of a solid body of water being driven aft, a certain proportion will be thrown uselessly into the air, with a motion at right angles to the progress of the boat.

APPENDIX.

Since this paper was prepared for last year's Summer Meeting in Belfast, the partially immersed screw-propellers have been applied to a pleasure boat, the "Pioneer," built in Newry for the purpose of developing the holiday traffic in the neighbourhood of Warrenpoint and Rostrevor on Carlingford Lough. In this estuary, situated among the mountains and celebrated for its scenery, the receding tide leaves flat shores inaccessible except to row boats; and to navigate by an ordinary steamer was found impracticable, as landing could be effected only at or near high water. The "Pioneer," carrying a Board of Trade certificate for 166 passengers, has accordingly been built so as to be suitable for shallow water, drawing only about 1 ft. 10 ins. forward and 2 ft. 10 ins. aft; her twin screws dip into the water to the extent of only 2 ft. 3 ins., although their diameter is 4 ft. 10 ins. She is fitted with two high-pressure engines, having cylinders 5½ inches diameter and 5 inches stroke, which drive the propellers through skew gearing 3 to 1, working in oil; the boiler pressure is 75 lbs. per square inch. Two photographs are given of this boat. One was taken from the pier at Rostrevor, Plate 22, with a party of the Institute of Journalists on board. The other was taken from Warrenpoint dock, Plate 23, as the boat was leaving with the members of the Irish Clearing House on board. The tourist season being so short, the boat has been got up without expenditure in decoration; her cost all complete, including Board of Trade requisites, was about £650. Her speed is 6½ miles per hour, with 16 to 17 indicated horse-power developed. During the nine weeks she was at work she carried about 13,000 passengers, with satisfactory financial result. Great earning power arises from the fact that the machinery occupies so little space, and consequently the deck is clear for passenger accommodation.

The following analysis, Table 3 (page 114), has been supplied of the working of the steam lighter "Hilda" during the first three months of 1896. This vessel, built of steel, is 60 feet length, 14½ feet beam, and 6½ feet depth; she had just been completed at the time of the author's former paper at the Manchester Meeting (Proceedings 1894, pages 365–7 and Plate 86). Since these particulars were compiled, water-ballast tanks have been put in her, so that now she can pass under the low bridges without other ballast, and consequently can make more voyages in a given time. She has a crew of two men working daytime only; and her full cargo of wheat or flour is 75 tons.

TABLE 3.

Analysis of working of Steam Lighter "Hilda,"
for January, February, and March, 1896.

Lighter 60 feet length, 14½ feet beam, 6½ feet depth; built of steel.

	Number of round trips	11
	Miles navigated, 50 × 2 × 11 =	1100
	Locks passed, 28 × 2 × 11 =	616
Cargoes carried	To Belfast, chiefly sand ballast,	173 tons.
	From Belfast inwards	784 tons.
	Total	957 tons.
	Freight average from Belfast 3*s.* 6¾*d.* per ton.	
	Income total	£174 15*s.* 8*d.*
	Expenditure total	£112 19*s.* 10*d.*
	Profit on eleven voyages	£61 15*s.* 10*d.*
Expenditure, including tolls.	Total on inward cargoes 784 tons,	£73 19*s.* 4½*d.*
	Per ton per 50 miles 1*s.* 10½*d.*	
	Per ton per mile 0·45*d.*	
Expenditure, excluding tolls.	Total on inward cargoes 784 tons,	£43 16*s.* 0*d.*
	Per ton per 50 miles 1*s.* 1½*d.*	
	Per ton per mile 0·27*d.*	
Coal, Oil, and Cotton Waste, total		£19 5*s.* 0*d.*
	Per ton per mile 0·059*d.*	

Models are exhibited of different modes of applying these adjustable screws. One is that of a narrow canal boat of 72 feet length, 7 feet width, and 3 feet draught. Another is a section of a boat of 60 feet length, 13½ feet beam, and 4 feet draught. Others are models of propellers and frames, Figs. 14 to 16, Plate 24.

Discussion.

Mr. Barcroft showed photographs of the "Pioneer," and models of canal boats and of large-bladed propellers, and of the frames in which the propellers were adjusted for the depth of immersion required.

Mr. Sydney W. Barnaby said that, although he had not had the pleasure of seeing any of the canal boats described in the paper, he took an interest in the use of screws for their propulsion, and should like to mention some of the points on which his own views differed from those of the author in regard to this subject. A good deal of stress had been laid upon the advantage of large screws as compared with small ones. Large and small were relative terms. In the steam lighter "Tyrone," described in Table 2, it would be seen that the screws were 4 ft. 10 ins. diameter; and even if these were wholly immersed, he should call them small screws, having regard to the large resistance of the boat and to the slow speed at which she was propelled. Placed as they were with three-eighths of their disc area out of the water, he should call them very small screws; and he was certainly surprised to find that they propelled as well as they did. As the resistance was not given, it was not possible to get at the propulsive coefficient for the boat, that is, the ratio between the power it would take to tow the boat and the power it took to drive it. But assuming the displacement, which also was not given, to be about 100 tons—and from the dimensions of the boat he thought it could not be more—and taking the speed through the water and the horse-power, which were given in the table, he found that the Admiralty coefficient, $V^3 \times D^{\frac{2}{3}} \div$ I.H.P.—that is, the cube of the speed in knots, multiplied by the cube root of the square of the displacement in tons, and divided by the indicated horse-power—was not a high amount; in the first observation in Table 2, for 4·09 miles per hour, which was equal to 3·55 knots, and 15·6 H.P., it would be only about 62. That was a fairly good efficiency: but there was nothing remarkable in it, he should say, for a boat of this sort.

(Mr. Sydney W. Barnaby.)

Although without experience in designing screws for barges, he should nevertheless have thought that better results would have been obtained from a pair of screws wholly immersed, overlapping if necessary, and of as large a disc area as could be got into the draught of water, which would be 50 per cent. more than the joint effective disc area of the two partially immersed screws; he did not know whether the author had tried this, and had found that it was not so. The use of snow-shoes for reducing the labour of walking on snow, and of broad wheels for moving heavy loads on soft ground, afforded hardly a fair illustration, he thought, of the advantages of large screws. Ships were propelled by moving water backwards; and the momentum of the water moved backwards must be equal to the momentum of the ship moved forwards. There was no analogy between this action and that of a man walking with snow-shoes, because he did not walk forwards by pushing the snow backwards. The advantage of snow-shoes, he thought, must lie merely in saving the labour of lifting the feet out of the snow, into which they would otherwise sink. For almost the same reason he took exception to the statement in page 106 that with large screws the water refused to move away backwards. Understanding what was meant, he thought it would be better to say that a large screw moved a larger amount of water backwards at a lower speed; this was the true advantage that a large screw possessed.

Then also as to reducing the wash on the banks, he could not see that the screw had anything to do with it. The wash upon the banks must surely be due to the shape of the boat and to the speed at which it was driven; with the same boat he believed the wash on the canal banks could not be reduced by any change of screw, but only by driving the boat slower. Had he to design the screw, he should like indeed not only to design the barge too, but also to determine the section of the canal. Looking at some of the canal sections shown in Plates 17 to 20, it was evident that, whatever screw was put behind the barge, the latter must be propelled very slowly indeed, or else the banks of the canal would suffer.

As to the effect of air drawn down by the screws (page 112), several years ago he had assisted Mr. Thornycroft in making a large number of screw experiments, some of which had been carried out for the express purpose of determining this very point. It had then certainly been found that, if air got down to the screw, the change in the relation of the power used in driving the screw to the thrust of the screw was remarkable, and much greater than could be accounted for by a mere reduction in area through partial emergence of the screw; in fact a great reduction of thrust could be obtained in a screw without its blades emerging from the water at all. In some of the experiments made, a small tube open at both ends had been carried down from above the surface of the water, with its lower end bent horizontally backwards to face the front surface of the screw. When the screw revolved in the forward direction, it drew air down through the tube, and the falling off in thrust was immediately most marked. It was not necessary for the screw to emerge from the water at all. No change was made in the blade area immersed; the only change was that air got down to the front face of the screw. The propelling action of a screw consisted partly in thrusting water astern by its after face, and partly in drawing water astern by its forward face; but in order to do the latter, the pressure of the atmosphere must be called into play. If air was allowed to get down in front of the propeller, the pressure of the atmosphere upon the water surface was balanced, and all the force then available for causing the water to flow towards the forward face of the screw was the weight of the head of water over it, which would not suffice to make the water flow more than slowly; it was easy to calculate at what speed it would flow. Under such conditions a screw was in fact more like an inclined paddle-wheel. The paddle-wheel was an exceedingly good propeller; but the propelling surface required to be much larger than the surface of an immersed screw, in order to give the same thrust and efficiency. If it were desired to work with these partially submerged screws at high speeds, they must be looked upon more as paddles, and must be considered as propelling almost entirely by thrust, that is, as propelling with the after surface only, instead of with the forward face also. Turning now to the partially immersed screws dealt with in the paper, it was seen from Table 2 that those on the "Tyrone" dipped

(Mr. Sydney W. Barnaby.)

into the water 3 feet, and the highest speed of the boat through the water was about 3½ knots. If the mean depth of the screw were taken to be about 1½ foot below the water surface, it would be found that under the action of gravity alone the rate at which the water would flow towards the forward face of the blades, being equal to the square root of 2 $g\,h$, would amount to about 6 knots. Now that portion of the propeller blade in the "Tyrone" which was situated at a depth of 1½ foot below the water surface he found was moving along a spiral path through the water at a speed of only about 5½ knots: so that as a matter of fact air did not want to get down, and did not get down; and he was therefore quite prepared to believe that these partially immersed propellers on the boats described in the paper suffered but little if at all from air getting down. But he had no doubt that, if the boats went faster and if the propellers revolved faster, another state of things would be found to arise: the air would go down, and the efficiency would be greatly diminished. The screws were efficient at the slow rate at which they were actually working.

The PRESIDENT, in calling upon Mr. Thornycroft, who though an old Member of the Institution had only just been elected a Member of Council, was sure he was expressing the views of all the Council when he said how highly pleased they were to welcome his advent among them, because they were well aware he would do everything that lay in his power to advance the interests of the Institution.

Mr. JOHN I. THORNYCROFT, Member of Council, referred to the backward current, also called in the paper the displacement current, about which it was surmised in page 105 that possibly it might exist even in open water. The head of water that was piled up in front of the barge really existed, as described in page 106; but it was also represented (pages 103–4) that the propeller was working with unabated energy in the induced current due to this head; and it was added (page 104) that "in this current the barge floats, and is carried with it in a backward direction, just as she would be if stemming or ascending the current of a river." This was not correct. The water piled up at the bow resisted the motion of the vessel by its increased pressure, which also gave rise to a current flowing aft alongside the hull; but at the stern the water again rose above the normal level, and the current flowing aft was again converted into pressure, which formed a stern wave of water having a temporary motion in the same direction as the vessel. It was in this forward current at the stern that the screw propeller actually worked; and this wave also had the effect of exerting a forward pressure on the vessel, to some extent balancing the resistance due to the wave at the bow. In a confined section of water, such as was unfortunately met with in the canals both in this country and in Ireland, the backward current flowing past the sides of the boat was greatly increased, due to the boat trying to work like a loose piston in a tube of water with its further end stopped up, which was not favourable to forward progress of the piston or the boat. This backward current always existed; but at the stern there was also a following current which must not be ignored; and probably the slip of a screw propelling a boat in a canal was much greater than might have been anticipated from the experience gained in open water.

The plan of inclining the propeller shaft to the line of motion of the vessel as seen in plan, when the propeller was partially immersed, was in his opinion a proper expedient. He had seen propellers used abroad, nearly corresponding with those represented in Plate 24, and in Fig. 5, Plate 89 (Proceedings 1894). They were used partially immersed, and he had heard with advantage.

As to why the air was not drawn down by these propellers, Mr. Barnaby's explanation (page 118) he thought was perfectly correct. Canal boats had to be propelled at such slow speeds that this difficulty had not cropped up. With higher velocities new conditions arose; and a point was arrived at when not only was the pressure of the atmosphere required for accelerating the water to keep up with the propeller, but, if the screw blades were not wide enough, the sum of the atmospheric pressure added to the force of gravity might still be insufficient for maintaining a supply of water to the screw. In some of the experiments made by Mr. Barnaby and himself a breakdown had occurred, which could not be accounted

(Mr. John I. Thornycroft.)

for until they suspected that this was what was the matter. It had been named by Mr. R. Edmund Froude "cavitation," and occurred when the pressure of the air and the head due to the depth of immersion were no longer sufficient for keeping up the supply of water to the propeller.

On the Thames he had seen a barge working well with inclined paddles. The designer seemed to have come to the conclusion that by putting a paddle shaft at an angle less than 90° to the centre line of the vessel in plan, and then putting the floats or blades at an angle to the shaft, a propeller would be obtained which was neither a paddle nor a screw, but which nevertheless would work well. The floats at the bottom part of their revolution were at right angles to the centre line of the vessel in plan, and therefore exerted their full effect in propelling; while in their highest position they were inclined to her beam at double the inclination of the paddle shaft to her beam. The propeller was thus something between a screw and a paddle.

There was yet another solution to the difficulty of getting propulsion in shallow draught, and that was by adopting a form of stern which would enable the water to be piled up over the screw by atmospheric pressure; when this was done, a large screw could be wholly immersed even with a limited draught. Many years ago he had designed for the Bridgewater Canal a tug in which he had arranged a completely immersed screw of 5 feet diameter to work in only 3 feet draught of water; and from some experiments which he had made he had satisfied himself that it would so work. But his plan was submitted to a local engineer, who had decided that it would not work; consequently nothing came of it. Since that time, having again had an opportunity of making sure that it would work, he had approached one of the London canal companies; but they had told him the towing of boats on canals was so much a commercial matter that they could not see their way to use steam, owing to its expense; they found it cheaper to buy donkeys, which would do all that was wanted, and did not cost anything for food, because they could pick up all they needed while the boats were going through the locks.

Mr. WILLIAM SCHÖNHEYDER pointed out that the oblique paddle-shaft mentioned by Mr. Thornycroft (page 120), having floats equally oblique to the shaft, so that when immersed they were square with the line of the vessel, was on the same plan as the driving gear of a planing machine made by Mr. Sellers of Philadelphia. An oblique shaft there carried a pinion with skew teeth, which geared into a longitudinal rack with square teeth upon the travelling bed of the machine. It worked perfectly well, and seemed therefore to afford ground for a presumption that the skew paddle-wheel would do the same.

Capt. T. BRIDGES HEATHORN had been working in a somewhat different direction in regard to propulsion; and he thought there was a great deal to be learnt in watching the effects of keeping the boss of a screw out of the water, and only the ends of the blades immersed. If screw propulsion could be accomplished in a way like this, it seemed to him that a great deal of difficulty would be overcome which was at present encountered in pulling the mass of the boss through the water, all to no good purpose. Moreover a vessel going at any speed through a canal threw up the water in front, which cannoned upon the bank on each side, and came back with some force upon the screw; this he thought had as much to do with checking the propeller as anything else.

Mr. J. HARTLEY WICKSTEED, Vice-President, having been one of those who at the Belfast meeting last summer had joined the excursion to Carlingford Lough, had had the opportunity of making a trip upon the lough on board the "Pioneer," which was fitted with a pair of the partially immersed propellers. Hence, although he could not speak of these propellers from a theoretical point of view, he could to some extent speak from actual observation, because he had been lowered into a little boat which followed close in the wake of the "Pioneer" and close to the propellers, and he had therefore been able to watch the way in which they entered the water and came out of the water, and the way in which they seemed to distribute the water. He had been much struck with the absence of any

(Mr. J. Hartley Wicksteed.)

splash: the propellers seemed neither to churn up the water, nor to drag any air in, nor to throw any spray out. They seemed just to cut like a knife through the water, and to push the vessel along. The wake at the back of the boat kept in parallel lines; it did not spread itself out. Nor did there appear to be any race of water going aft, as far as could be observed by means of small floating substances dropped upon the water at the stern. The propeller blades appeared to act perfectly well, so far as his own observation went.

The opinion expressed by Mr. Barnaby (page 116)—that a wholly immersed screw would have a larger disc area to act upon the water than could be obtained with a propeller partially immersed—was one which he confessed himself unable to follow. It appeared to him in principle that for any given depth of immersion it would always be possible to design a partially immersed propeller which would give more hold upon the water than one completely submerged (Proceedings 1894, page 379, and Fig. 12, Plate 91).

The shafts of the partially immersed propellers on the "Pioneer" were stated (page 113) to be driven through skew gearing, three to one, which he believed was the same that was sometimes called right-angled gearing, when both wheels ran at the same speed, having the same number of teeth. In the latter case the teeth would be at angles of 45°; and he asked what were their angles when the speed was three to one. Even with the right-angled gearing and the teeth at 45°, it appeared to him that whatever was bad for the propeller was also bad for the gearing. For the propeller it had been argued (page 101) that it was bad to have any part of the blade inclined at an angle of more than 45° to the beam of the vessel, because beyond that angle the greater part of its action would be transverse to the direction of the vessel's motion. Now in the use of skew gearing there was the same sort of action; and he considered there must be the same objection to the angle of 45° for the teeth that there was to having so steep an inclination for the blade surface in the propeller. Therefore even supposing that no exceptional result had been achieved in the "Tyrone," for which Mr. Barnaby had calculated (page 115) that the Admiralty coefficient would be only about 62, he thought this would not conclusively invalidate any argument in favour of the partially immersed propeller at such low speeds, because some portion of the want of efficiency might here be accounted for by the loss arising from the transmission of power to the propeller shaft through the right-angled or skew gearing.

Mr. E. KILBURN SCOTT showed an electric propeller, not yet applied to a canal barge, but of which there had been a good deal of experience in launches on the Thames, and which was now going to be applied to boats on the Norfolk Broads. It was a rudder-motor, as shown in Plates 25 and 26; and the specimen exhibited, which had been made by the Edison-Swan Co. for the inventors, Messrs. New and Mayne, was of 2 horse-power. At this power it would work safely, although it looked small; because the output of an electric motor was to a great extent limited by the heating of the copper wires, and in this instance the motor itself being entirely submerged in the water was thereby kept cool. Running in air it would give much less power than in the water. It seemed to be a form of motor which could be applied to existing barges with but slight structural alteration. It would be simply carried in a frame fastened to the rear of the barge, and by means of a right-and-left-hand screw the axis of the propeller could be tilted in a vertical plane to any desired angle. In that way the subsidence of the hind part of the barge could be annulled, being neutralised by tilting the propeller so as to give a slightly lifting action. Thus far the motors had been driven by means of accumulators; but where available a current of electricity could be taken into the barge by trolleys running on overhead wires carried along the canal bank, in the same way as on electric tramways. The accumulators however, though they had not been successful hitherto on electric tramways because of the great vibration to which they were there subjected, were quite successful in boats, at any rate on canals and rivers and fairly still water, where there was practically no vibration at all. The weight of the accumulators for driving a pair of 2 H.P. motors of this kind applied behind a barge, as shown in Plate 25, would not

(Mr. E. Kilburn Scott.)

be more than 3 tons for a run of 18 hours at 2 miles an hour. Two 4 H.P. motors would require about 5 tons of cells for the same distance; and in a barge carrying 30 tons this was but a small percentage. The individual motor exhibited of 2 H.P. did not weigh more than 2½ cwts. The main outside casting carried the armature, which was thus a stationary armature, Plate 26, while the pinion of the gearing driving the propeller was attached to a revolving field. The stationary armature had been adopted here, because thereby the armature conductors were brought closer to the water; and the commutator, which was also stationary, was readily got at, being just above where the tiller handle was attached to the pillar. By means of racks or slides, as shown in Plate 25, the propeller could be kept always just below the surface of the water, whatever the load in the boat might be. The specimen exhibited ran at a good speed; but in a barge it would be geared down slower by means of the gearing enclosed inside the casing; and the Friedenthal propeller shown in Plate 25, being of large diameter, say 2 or 3 feet, would run at about 200 revolutions per minute. It might be thought that the employment of accumulators on canal boats would be difficult, because of the need of resorting to charging stations; but he believed that as a matter of fact almost 80 per cent. of the central electric stations in this country for the public lighting of towns were placed on the banks of canals, simply because the canal water was wanted for feed and condensing, and also because the coal supply generally came by canal. Such stations therefore could put accumulators on barges to carry them on for 18 hours at 2 miles an hour, that is 36 miles; at the end of which time they would have got to another station. Even if this were not so, it would probably pay the canal owners to have small electric stations for this purpose, where the public supply stations were too far apart. Already the Leeds and Liverpool Canal Co. were proposing to put up a station at Bingley for generating electric power by means of the fall of water at the five-rise and three-rise locks; and they had proposed to supply electric current to the Bingley district council at 4*d.* per Board of Trade unit.* At

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* "The Electrician," 22 January 1897, page 409.

Burnley, Leeds, St. Pancras, Hanley, and Norwich, electric current was being sold at 3*d.* per kilo-watt hour or per Board of Trade unit, and in Huddersfield and Manchester at 2½*d.* Even at these prices a profit was being made, because what was chiefly wanted by electric lighting stations was a day load; and the charging of accumulators was a day load of exactly the kind which they required, and for which it would pay them to give preferential rates.

Mr. Leslie S. Robinson said that after the remarks of Mr. Barnaby and Mr. Thornycroft it was only natural to be careful about expressing any opinion which would seem in any way to traverse theirs. Like Mr. Wicksteed, he had had the opportunity of seeing some of these partially immersed propellers at work; and he thought that a good deal of the criticism which had been so ably offered had arisen from the fact that the two authorities who had spoken on the subject had derived their opinions from their own experience of such magnificent speeds as 31 or 32 knots an hour; whereas canal boats were practically doing only 2 or 2½ miles an hour. Here he had found a province was entered which he must confess was totally different from what he had himself expected, or from anything which theory apart from experience would have led him to anticipate. For instance, few marine engineers, he imagined, realised what a reduction in section of waterway meant in regard to power exerted. Looking at the diagram, Fig. 20, Plate 27, it would be seen that, while the ratio of the section of canal to the immersed midship section of the boat was reduced by only about one-third, as shown by the line CC, the resistance RR rose to nearly double, even for a boat going so slowly as half a mile an hour. On the other hand, in the opener water of the river Seine, while the ratio of the sections was reduced by more than one-third, as shown by the line SS, the resistance *rr* of the same boat at the same low speed hardly rose at all. This would serve to show how far different was a canal boat moving in a canal from a boat running in open water. Then again, looking at the diagram Fig. 21, there were three canal boats varying in length from about 124 feet to about 67 feet, but as nearly identical as possible in all other

(Mr. Leslie S. Robinson.)

respects; and the diagonal line showed that the actual resistance of the three boats, as ascertained by practical experiments in towing them at speeds of from $1\frac{1}{8}$ to $5\frac{5}{8}$ miles an hour, was absolutely identical. This was a fact which he was sure neither the late Mr. Froude, nor Mr. Barnaby, nor Mr. Thornycroft, would ever have dreamed of, any more than himself. Reasoning from theory, the very opposite would have been expected. A good deal of the criticism he therefore thought had arisen from reasoning, which, though undoubtedly correct for open water, did not hold for canals.

The partially immersed propellers described in the paper were probably not all that could be desired; but they had certainly done a considerable amount of good work. The wash was very little; more than thirty years ago Pole's experiments had shown that up to three miles an hour no damage was done to the canal banks by the wash. The partially immersed screws were no doubt a hybrid plan, a cross between the stern wheel or paddle wheel and the ordinary wholly immersed screw. As to air being drawn down by the propeller, it had been clearly explained by Mr. Barnaby (page 118) why this question did not arise in the propulsion of canal boats. In corroboration of Mr. Thornycroft's able experiments (page 117), careful practical experiments had been made in the same direction by M. Normand. They consisted in suspending from a crane in a dock a full-size torpedo-boat with her nose abutting against the dock wall, where there was a measuring apparatus fixed for recording the pressure against the wall. The engines were then run at various speeds, while the stern of the boat was gradually raised until the propeller began to cut the surface of the water and to draw air down; and immediately that this happened, the pressure of the boat against the dock wall fell off rapidly. No such difficulty had been experienced with the partially immersed propellers described in the paper, merely because they were running at a speed so low that the air question did not come in at all.

As to the backward current alongside the boat, and the after-current following her, the passage of a boat through a canal had been aptly compared by Mr. Thornycroft (page 119) to a loose piston trying to force its way along a tube of water with the further end blocked up. The comparison indeed was so far true, that, if the traffic was kept running in one direction on a canal, it had been found that after a day's work the water in the canal was higher at the further end and lower at the starting end. There was no doubt about the fact that a boat as it went through a canal forced the water up in front of it; owing to the restricted area there was created an artificial head in front, whereby was caused a backward current of considerable velocity along the sides of the boat, which of course would not take place if the boat were moving through open water. It was due he believed to this piston action of the boat that a good many of the unexpected results occurred which were met with in canal propulsion.

In Table 1 it would have been of much interest if the ratios of the cross section of the waterway to the immersed midship section of the boat could have been given. In their absence however it would be noticed that between locks 6 and 7, although the speed of the propellers was maintained, the speed of the boat dropped down to 0·95 mile per hour, instead of what it would be in open water, namely 3·27 miles per hour, as given in the bottom line of the table. This would show immediately how great an effect a reduced cross-section had upon the speed.

It would be borne in mind that dealing with canals and barges involved dealing with a class of men and a class of work altogether different from those connected with the higher class ordinary marine machinery or the higher class torpedo-boats; and the appliances adopted had to be suited to those who had to handle them. The latter were ordinary bargees, into whose hands it was impossible to put delicate and elaborate machinery; it had to be strong, simple, and light. Therefore the question which the author had had before him, he believed, had been to design, not the kind of machinery that would be put on board a fast-going boat, but the cheapest, lightest, most practical machinery that could be devised for fulfilling all the conditions existing on canals. Without by any means implying that finality had yet been reached, he thought that these large propellers, running so slowly as they did, pushing back a large volume of water

(Mr. Leslie S. Robinson.)

at a low velocity, and therefore producing practically but little wash upon the banks, had to a large extent got over some of the difficulties which surrounded canal-boat propulsion. All therefore who were interested in this question would cordially thank Mr. Barcroft for the enterprising and persevering way in which he had steadily worked on at the subject, and for having now brought the further results before the Institution.

Mr. BARCROFT said that, in propounding some of the questions which arose with regard to the use of these propellers, he did not wish to run counter in any way to the acknowledged principles of screw propulsion. A good deal of the theoretical knowledge of which he had made use had been derived from Mr. Barnaby's book on marine propellers; and he had acquainted himself with the experiments which Mr. Barnaby and Mr. Thornycroft had carried out. The great difference between the propulsion they had been accustomed to and that which he had had to deal with had been difference of speed. What was perfectly true with regard to higher velocities did not hold for low speeds.

In lieu of taking snow-shoes as an illustration of the advantage of large blades for a propeller (page 116), the example might be instanced of a person learning to row, whose first experience commonly was to find himself on his back in the bottom of the boat, in consequence of not having dipped his oar deep enough into the water to encounter a resistance equal to the effort he had exerted: the oar had not got hold of a sufficient volume of water to use up his own effort. The principle was the same in the use of the propellers: there must be a sufficient volume of water for the propeller blades to push back against; and this implied the adoption of large blades.

That an induced current was set up all round the immersed section of a boat passing along in a canal might be observed in localities where the water was clear and still and the sides and bottom were lined with weeds. The backward current could then be seen dragging the weeds into a horizontal position heading sternwards; and the weeds would be seen to retain this position till the boat had passed clear, when they again became erect, but gave no indication of a following or forward current (page 119) close to the stern of the boat. When the traffic on a canal went in one direction for a considerable length of time, the bargemen were all well aware of the fact mentioned by Mr. Robinson (page 127) that the water level fell in the rear of the traffic, and that with the same draft the passage of the later boats became more difficult; whether they were propelled by screws or hauled by horses the difficulty would be the same. This he thought proved that in a canal the water behind did not fall in so quickly or in the same way as it did in open water; but the water coming in behind he considered had no serious effect one way or the other upon the action of the propeller in a canal.

In the skew gearing of the "Pioneer," which was 3 to 1, the teeth in the driving wheel were inclined at an angle of 23° to the face of the wheel, and in the driven wheel at the same angle to the axis; and as far as he could judge the skew gearing did not absorb much of the power. Several of the boats were working with bevelled gearing, 3 to 1 and 3½ to 1; and so far as his observation went, as good a result was obtained from the skew gearing as from the bevelled.

Drawing air down was of course entirely a question of speed. If the partially immersed propellers ran at a much higher velocity, no doubt air might be drawn down, and there might be some loss of efficiency from that cause. But at present at any speed at which the propellers had been going there had been no loss. Mr. Wicksteed, who had seen the propellers running at about 100 revolutions per minute, had noticed (page 121) that the water was quite solid or unbroken, and that there was no air drawn down and no water thrown up.

While most engineers might like to design not only the screw but also the boat and the canal section (page 116), this was exactly what could not be done; and the problem was restricted to the application of mechanical power to existing boats on existing canals, so that they might navigate independently of horses or other extraneous power. This question had been fully dealt with in his former paper read at Manchester in 1894, and the chief reason of the necessity for having the propellers adjustable in depth of

(Mr. Barcroft.)

immersion had then been explained: namely, in order to suit the two conditions of navigation, when the boat was full with deep draught, and when empty with light draught. Experience had shown that propellers such as those described and now in use suited all conditions of draught and all kinds of section of waterway. It was important to know on such high authority as that of Mr. Barnaby that no fault was to be found on scientific or technical grounds with the efficiency of the partially immersed propellers when applied as described in the paper.

Referring to Capt. Heathorn's remarks (page 121), the "Pioneer" worked with the bosses of the propellers above water. Practical experiments had extended over many depths of immersion, and many changes of pitch and diameter: in consequence of which, since the former paper in 1894, improvements in detail had been made, resulting in less weight of the propellers with greater strength, and with a considerable gain in regard to appearance.

The President was sure the Members would consider that Mr. Barcroft deserved their hearty thanks for his most interesting paper. It had led to an instructive discussion, in which the subject had been pretty exhaustively dealt with.

MEMOIRS.

Alfred Blechynden was born at Falstone, North Tyne, on 26th March 1849. After leaving school, he continued his education, while an apprentice, at evening classes in Newcastle-on-Tyne. In 1864 he commenced his professional life by being apprenticed to Messrs. J. and G. Joicey and Co., whence he went to Messrs. Robert Morrison and Co., and later to Messrs. Thompson, Boyd and Co., now the Wallsend Slipway and Engineering Co. He next went to Messrs. Palmer's Co.; and later on became a leading draughtsman, then head draughtsman, and subsequently engine works manager, at the St. Peter's Works of Messrs. R. and W. Hawthorn, Newcastle-on-Tyne. In 1884 he was appointed general manager of the Rio Tinto Copper Mines, which position he was obliged to resign in 1886 on account of ill health. Returning to England he carried out the trials of the French cruiser "Condor" at Rochefort-sur-mer on behalf of Messrs. Hawthorn; after which in June 1887 he was appointed head of the engineering department of the Barrow Shipbuilding Co., which became the Naval Construction and Armaments Co. At the end of 1895 he became general manager of the works of Messrs. John Penn and Sons, Greenwich. The chief work of his life was the designing of marine engines. Among these were the engines of the "Oruba" and "Orizaba," the "Empress of India," "Empress of China," and "Empress of Japan;" the last three were mail steamers for the Pacific service, both built and engined at Barrow. He also designed the machinery for several war vessels, of which the latest and perhaps the most important was the big cruiser "Powerful." The engines of the first-class battleship "Majestic" were planned and carried out by him. He designed the machinery for the second-class cruisers "Latona," "Naiad," "Melampus," and "Flora," for the third-class cruisers "Jaseur," "Jason," and "Niger," and for several torpedo-boats, and torpedo-boat destroyers; the latter were fitted with his water-tube boilers. The big sand-dredger "Brancker," built for the Mersey Dock and Harbour Board, was fitted with machinery of his design, which has done good work in clearing a passage through the Mersey bar. In 1891 he contributed to the Liverpool meeting of this Institution a paper giving a review of marine engineering during the preceding decade (Proceedings 1891, page 306). His death took place at his residence at Blackheath, London, from heart disease, on 20th February 1897, in his forty-eighth year. He became a Member of this Institution in 1881, and was also a Member of the Institution of Naval Architects.

AUGUSTUS HICKS HENERY BRATT was born at Demerara in 1863. He was apprenticed in 1876 to Mr. Leigh Howell, Bagillt Iron Works, Flintshire. In 1881 he passed brief periods in the works of some of the engineering firms in Manchester, and at the same time pursued a course of study at the Manchester Technical School. From June to October 1882 he was in the works of Messrs. Crossley Brothers; from November 1882 to May 1883 at the Oldfield Road Iron Works of Mr. John Cameron; from June 1883 to April 1884 at Messrs. P. R. Jackson and Co.'s Salford Rolling Mills; and from June 1884 to January 1885 at Messrs. Sharp Stewart and Co.'s Works. At the Manchester Technical School he was awarded the Mather exhibition 1885–1887, was bracketed equal for the Heywood exhibition 1885, and subsequently obtained a Whitworth scholarship and a bronze medal for metallurgy. In January 1886 he entered the service of the War Department at the Royal Gun Factories, Woolwich, and subsequently became an examiner of machinery there. In 1888 he went out to the Prye River Dock Co. in Penang; and in 1891 he commenced business as a consulting engineer in Shanghai, where his death took place on 17th March 1896, at the age of thirty-three. He became a Member of this Institution in 1888.

ROBERT CARR was born on 29th November 1827 at South Shields. After having served an apprenticeship there of seven years, from 1841 to 1848, to Mr. T. D. Marshall, mechanical engineer, he entered the employment of Sir W. G. Armstrong and Co., and was associated with the earliest work and development of hydraulic power by that firm, for whom he had charge of the erection of hydraulic machinery for the London and North Western Railway at Haydon Square depôt, Minories, London; for the Great Northern Railway at King's Cross; and for the St. Katharine Dock, London. He also assisted at the Great Exhibition of 1851 in the management of the supply of steam and hydraulic power, which the same firm had undertaken to provide. In 1856 he was appointed resident engineer to the St. Katharine Dock, where he had the responsible superintendence of all works, buildings, and machinery. On the amalgamation in 1865 of the London, St. Katharine, and Victoria Docks, the engineering of the last was added to his charge; and many important works, such as new jetties, buildings, and the remodelling of the swing bridge, were carried out under his direction. In 1869 the care of the London Dock was placed with him, and he became engineer to all the property of the London and St. Katharine Docks Co. In 1872 he was occupied in conjunction with Sir Alexander M. Rendel, at that time consulting engineer to the company, upon the preparation of plans and estimates for an extensive enlargement of the Victoria Dock, together with a new and deeper entrance into the Thames at Galleons Reach. On its completion in 1880 the care of this extension, now known as the Royal Albert Dock, also devolved on him. New tobacco warehouses and extensive granaries at the Victoria Dock were erected in 1883 under his superintendence; and in 1884 powerful pumping machinery was completed at Galleons, capable of delivering 125,000 gallons per minute, whereby the water in the Royal Albert Dock is maintained at high-water mark, or above it when required. In 1880 one of the earliest installations of refrigerating machinery was put up at Victoria Dock. The demand for cold storage of meat from abroad increased so rapidly that he had to enlarge the accommodation, and by 1892 the storage capacity had risen to 564,000 cubic feet, capable of holding 161,000 carcasses. He also prepared plans in 1884 for enlarging the Royal Albert Dock and its entrance, and for the construction of a river wharf; and the work was completed in 1886 without the aid of an outside contractor. In 1888, on the formation of the London and India Docks Joint Committee, he was appointed their first chief engineer; and in 1892 he prepared plans for a new entrance and enlargement of the basin at the West India Docks, Blackwall. In October of the same year he went to Liverpool to inspect some new pumping machinery; and on the return journey he sustained a slight stroke of paralysis, the result of overwork and mental strain. Although he was fortunately able to throw off the effects, his retirement was deemed advisable in order to avoid risk of a further illness. He was then appointed consulting engineer, in view especially of the completion of the Blackwall entrance, for the design of which he had been entirely responsible. This work was finished in September 1894, and shortly afterwards he retired on a pension. After a serious illness in December 1896, his death took place at Bournemouth on 6th April 1897, at the age of sixty-nine. He took a great interest in civic, local, and political matters; having been one of the first to be enrolled a volunteer, he retired in 1885 as honorary major. He was elected a Member of this Institution in 1877; and was also a Member of the Institution of Civil Engineers.

George Fletcher was born in London on 10th January 1837, and was the son of Mr. George Fletcher, Farnham Place Engine Works, London. He was educated at Nesbit's School and Chemical Laboratory, and at King's College. In 1854 he entered his father's works in Farnham Place, which were demolished in 1863, owing to the site being required for Southwark Street; and new works were erected under his supervision in Derby. In 1874 on the death of his father he assumed the charge of the works, which acquired a reputation for the manufacture of sugar machinery, Portland cement machinery, large sewage-pumping machinery, and mining and blast-furnace machinery. His death took place in Derby from internal hemorrhage on 23rd June 1897, at the age of sixty. He became a Member of this Institution in 1883.

Lavington Evans Fletcher was born at Henley on Thames on 9th June 1822. In 1839 he was articled to Messrs. Barrett, Exall, and Andrewes, Katesgrove Iron Works, Reading, with whom he remained nearly two years after his pupilage. While there he had charge of erecting the first engine, boiler, and biscuit machinery for Messrs. Huntley and Palmer's biscuit manufactory; and also superintended the erection of an engine, boilers, and pumps, for draining one of the shafts, 200 feet deep, of the Box tunnel in course of construction for the Great Western Railway. At this time economy of fuel in steam engines and boilers began to engage his attention, in connection with the repairs and adjustment of engines for various paper mills, among which were those of Mr. Spicer at Beaconsfield and Mr. Poulton at Alton. At Reading also he designed and constructed in 1842–3 a steam road carriage; but its running had to be given up, because so many horses took fright at it. Early in 1843 he went to Nassau in Germany for a short time. During the railway mania in 1845–6 he did a good deal of surveying for lines then proposed. In the five years 1846–50 he was engaged under Mr. I. K. Brunel as an assistant engineer upon the South Wales Railway at Swansea. Besides several bridges and tunnel fronts he designed the mechanical arrangements of the iron swing-bridges at Carmarthen and at Loughor. He also worked out the details and superintended the erection of the Landore viaduct, designed by Mr. Brunel, a compound structure of wood and iron trussing, a third of a mile long, and at that time one of the largest in the kingdom; it occupied about two years in construction, and five years after its opening in 1850 he gave a description of it to the Institution of Civil Engineers (Proceedings 1855, vol. xiv, page 492). It was the last of the old wooden viaducts to be replaced lately by an iron structure. On the completion of the South Wales Railway he became partner in London in 1851 with Mr. John Frederick Spencer, who had been his fellow pupil at Reading, and had acted as steersman of the steam road carriage in its runs thence. As consulting engineers they designed several iron screw steamers, and prepared plans for the engines and boilers, with a special view to economy of fuel. On the dissolution of the partnership in 1855 he had charge of the drawing office of Messrs. Gwynne and Co., Essex Street, Strand; and was afterwards engaged under Mr. Latimer Clark in designing and erecting an engine for exhausting the air from the pneumatic despatch tubes laid under some of the London streets. In 1861 he was appointed chief engineer, under the then title of chief inspector, to the association for the prevention of steam boiler explosions and for effecting economy in the raising and use of steam, which had been established in Manchester in 1854 under the chairmanship of Mr. William Fairbairn, and was afterwards known as the Manchester Steam Users' Association. In 1867 he conducted experiments to ascertain the result of injecting cold water into some circulating domestic boilers when red-hot, and found that no explosion ensued. With Dr. Richardson of Newcastle-on-Tyne he carried out in 1868 a series of trials, known as the Wigan Coal Trials, for the South Lancashire and Cheshire Coal Association, for the purpose of ascertaining the evaporative efficiency of the coals of those districts, and of showing their suitability for use in the navy. In 1874–76 he subjected to a series of hydraulic bursting tests a Lancashire boiler made from his designs, with a view to ascertaining the strength of various riveted joints and the value of different methods of strengthening the plate round manholes, as well as the value of cast-iron branches for fittings. In 1876 he contributed a paper to this Institution upon the Lancashire boiler, its construction, equipment, and setting (Proceedings, page 59). In the same year he acted as scientific assessor in investigating the fatal boiler explosion which occurred on board H.M.S. "Thunderer" on 14th July 1876. In 1881 he was concerned with the parliamentary enactment obtained by Mr. Hugh Mason, then president of the Manchester Steam Users' Association, providing for an enquiry and report by the Board of Trade upon every boiler explosion on land. In 1882 he carried out at Preston a further series of experiments, known as the red-hot furnace-crown experiments, upon turning cold water into a red-hot Lancashire boiler; these were far more elaborate than the earlier in 1867, and with the same result that no explosion occurred. Early in the present year his health broke down, and after temporary recovery his death took place on 14th June 1897 at the age of seventy-five. He became a Member of this Institution in 1867, and was also a Member of the Institution of Civil Engineers and the Manchester Association of Engineers.

William Wilson Hulse was born at Amber, Derbyshire, on 19th June 1821, being the second son of Mr. Joseph Hulse, cotton spinner, and younger brother of the late Mr. Joseph Sykes Hulse, machine-tool maker. After being educated at King's College, London, he was apprenticed at an early age to his cousin, Mr. Joseph Whitworth, of Manchester, with whom he remained for a considerable period. He ultimately became managing partner, and remained in that position until the business was converted into a company. During that period he initiated the hollow frame now so largely adopted for machine-tools. After practising for several years as a consulting engineer, on his brother's retirement from business in 1881 he took over the Ordsal Works, Manchester, and re-designed and brought up to date the machine-tools made there. He also introduced many improvements, of which a few were referred to in his paper read before the Institution of Civil Engineers in May 1886. In 1875 he acted as one of the British judges at the Philadelphia Exhibition, and subsequently in a similar capacity at others. His death took place at his residence at Withington, near Manchester, on 20th March 1897, in his seventy-sixth year. He became a Member of this Institution in 1864; and was also a Member of the Institution of Civil Engineers.

Frederick Colthurst Kelson was born in Bristol on 13th May 1831, being the son of Mr. Joseph Kelson, surgeon, of that city. He was educated at Bristol College, and served his apprenticeship with Messrs. Pritchard, of Gravesend. After a varied and useful experience he entered the Royal Navy, serving as engineer from 1860 to 1865 in H.M. ships "Caradoc," "Fisgard," "Antelope," and "Donegall." On leaving the service he was engaged for some years with Messrs. George Forrester and Co., Liverpool, until in 1869 he was appointed superintendent engineer of the home section steamers of the Cork Steamship Co., with the management of their yard and engine works at Cork. About 1870 this company was divided into two, the Cork Steamship Co. retaining the foreign-going steamers sailing out of Liverpool, while the newly formed City of Cork Steam Packet Co. took over the cross-channel steamers sailing from Cork.

Later on the latter sold their works at Cork, and he returned to Liverpool, where he established himself as a consulting engineer. On the death of Mr. Crichton in 1878, he succeeded him as superintendent engineer of the Cork Steamship Co. During the earlier part of this time he also acted as consulting engineer to the City of Cork Steam Packet Co., designing and superintending the building of some of their steamers, as well as for other steamship owners. As a skilful, sound, and successful engineer and naval architect he was widely known and highly esteemed amongst engineers and shipbuilders. His death occurred suddenly at his residence in Waterloo Park, Liverpool, on 10th July 1897, at the age of sixty-six. He became a Member of this Institution in 1873.

BENJAMIN MARSDEN, born in Manchester on 25th November 1838, was the elder son of Mr. Samuel Marsden, by whom the Manchester Bolt and Nut Works were established in 1845. Under his father he acquired there a thoroughly practical knowledge of the business, which for the last thirty years was entirely in his own hands. His invention of a bolt-heading machine gave an impetus to machine bolt-forging, and with it he made use also of several other bolt-forging and nut-making machines. Machine-tool making for bolt and nut manufacture was gradually added to the business, and about thirty descriptions and sizes of tools were constructed, giving employment to about 400 men. For the large lock-gates and other works on the Manchester Ship Canal, most of the bolts and tie-rods used were manufactured at his works. As a result of visiting the United States he introduced an oil-fuel furnace, which was adopted throughout the works for the forging of bolts and nuts by machinery. After some years' suffering from bronchial troubles, his death took place after a short illness on 30th January 1897, at the age of fifty-eight. He became a Member of this Institution in 1887; and was also a Member of the Iron and Steel Institute.

WILLIAM PUTNAM was born in London on 17th December 1835. At an early age he went north, and since then had been closely identified with engineering operations on the north-east coast. He served his time in the works of the old Stockton and Darlington Railway at Shildon; after which he went to Carlisle to join the firm of Messrs. Cowans, Sheldon, and Co. About 1862 he went to Darlington to manage the Darlington Forge, employing at that time 50 or 60 men; these works have so increased as to give employment now to over 800 men. In 1873 he was appointed managing director. On his first taking charge of the Forge, it was principally engaged upon railway work; but owing to the increase in the number of ships built of iron and steel, he added heavy machinery for meeting the growing requirements of marine engineering and shipbuilding. The works were thereby enabled to turn out crank-shafts, tail-shafts, stern frames, rudders, keels, propellers, and other work for the largest and heaviest ships of the British and other navies, and for the Cunard, Peninsular and Oriental, and other lines, as well as forgings and castings up to 50 tons for engine works and collieries. His interest in local matters led to his being for a time a member of the Darlington Town Council. His death took place suddenly at Bournemouth from syncope on 1st May 1897, at the age of sixty-one. He became a Member of this Institution in 1866; and was also an original Member of the Iron and Steel Institute.

Edward Philpot Senhouse Quirk was born at Great Easton, Uppingham, on 22nd December 1850, being the son of the Rev. George Quirk of that place. He was educated at King William's College, Castletown, Isle of Man, and at the Lancaster Grammar School. He served a five years' pupilage from 1869 to 1874 in the marine-engine works of Messrs. R. Napier and Sons, Glasgow, and then went to sea as fourth engineer for six months. From 1874 to 1876 he was leading draughtsman in the marine-engine department of the Barrow Shipbuilding Co., and for five months in 1877 a leading draughtsman in the engine department of Messrs. John Elder and Co., Fairfield Works, Govan. From July 1877 to December 1892 he was assistant mechanical engineer, and from January 1893 chief mechanical engineering assistant under Sir James N. Douglass, F.R.S., the late engineer-in-chief to the Trinity House, and latterly under Mr. Thomas Matthews, the present engineer-in-chief. His death took place at his residence at Peckham Rye, London, on 30th June 1897, in his forty-seventh year. He became a Member of this Institution in 1893.

RICHARD CHRISTOPHER RAPIER was born at Morpeth on 7th June 1836. After serving an apprenticeship with Messrs. Robert Stephenson and Co., Newcastle-on-Tyne, he became associated with Messrs. Ransomes, Ipswich, who at an earlier period of their history combined the businesses of agricultural and railway engineers. In 1868 the two classes of business were divided. New works were designed by him for the railway business, which were started in 1869 as the Waterside Iron Works, under the name of Ransomes and Rapier. The firm was converted into a company in 1896, of which he was managing director. In 1878 he published a book entitled "remunerative railways," advocating the use of light railways of narrow gauge for opening out new countries; this has become a standard work of reference. Shortly afterwards he published another book on "fixed signals of railways, and the working of the fast and slow traffic," at the time when the idea of separate lines for goods and passenger traffic had been suggested, which has now become generally adopted by the main lines of railway. In 1872 he interested himself in introducing railways into China, and in conjunction with Messrs. Matheson and Co. had a share in the construction of the Shanghai and Woosung Railway. He was one of the chief promoters of the narrow-gauge railway of 3 feet gauge from Halesworth to Southwold, of which he eventually became the chairman. The improvement of river navigation was another subject to which he devoted much time and energy, in conjunction with the late Mr. F. G. M. Stoney. His firm equipped the Manchester Ship Canal with all its large sluices, and also constructed the large sluices at the entrance to the river Weaver, and the movable weir on the Thames at Richmond, and the much larger movable weir now in course of construction on the Clyde at Glasgow. He was one of the principal movers in the search for coal in Suffolk and Essex, and was chairman of the association for that purpose. After he had been for some months in ill health, his death took place at Folkestone on 28th May 1897, in the sixty-first year of his age. He became a Member of this Institution in 1873; and was also a Member of the Institution of Civil Engineers, and of the Iron and Steel Institute.

Joseph Ruston was born on 12th February 1835 at Chatteris, Cambridgeshire. Having served his time with Messrs. Wostenholm and Son, Washington Cutlery Works, Sheffield, he began business as a millwright in a small way at Lincoln in 1857. By dint of great energy he built up a large engineering concern, which was converted into a company in 1889. From 1857 to 1897 the works produced 20,800 engines, 19,700 boilers, 10,900 threshing machines, and 1,350 corn mills, in addition to a number of other miscellaneous implements. It was largely by cultivating a foreign connection that these results were obtained. At the Lincoln Meeting of this Institution in 1885 he contributed a Paper on Dunbar and Ruston's steam navvy (Proceedings 1885, page 349). In municipal affairs he took a great interest, and became councillor, alderman, justice of the peace, and mayor of Lincoln; and for some years he represented that city in parliament. He had conferred upon him the cross of the Legion of Honour, and the Order of the Osmanieh. His death took place at his residence in Lincoln on 10th June 1897, at the age of sixty-two. He became a Member of this Institution in 1867.

Alfred Louis Sacré was born in London on 6th April 1841. Having been educated at a grammar school in Marylebone, he became a pupil in 1857 of Mr. Archibald Sturrock in the locomotive department of the Great Northern Railway at Doncaster. On the completion of his term he had charge of the works at Peterborough, and later on had full charge of the Peterborough district. On the formation of the Yorkshire Engine Co. at Sheffield he was engaged as works manager, and subsequently rose to the positions of manager and managing director. In 1871 he became manager of the Avonside Engine Works in Bristol, and proceeded later to

Russia on their behalf. On his return he commenced business in 1877 on his own account in London as consulting engineer. In 1882 he became also manager of the Vacuum Brake Co., and subsequently managing director. His death took place in London on 25th July 1897, at the age of fifty-six. He became a Member of this Institution in 1866.

Frank Walter Scott was born in London on 3rd November 1864. Having been educated at Worthing and King's College School, he served an apprenticeship from 1881 to 1883 with Messrs. Langen and Hundhausen, engineers, Grevenbroich, Rhenish Prussia, afterwards remaining a year with them as draughtsman. In 1884 he entered his father's engineering business, Messrs. George Scott and Son, Whitechapel, London, and in 1888 was taken into partnership. He designed and constructed the gas-compressing machinery for Professor Dewar at the Royal Institution, and made several improvements in hydraulic machinery &c. Ill health, brought on by overwork, compelled him to give up business; and he died at Totland, Isle of Wight, on 22nd July 1897, in his thirty-third year. He became a Member of this Institution in 1891.

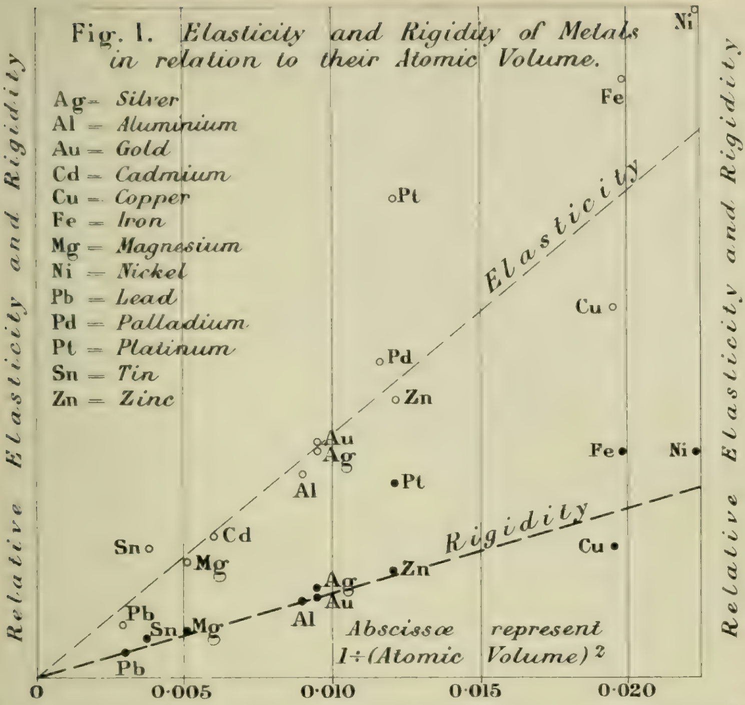


Fig. 1. *Elasticity and Rigidity of Metals in relation to their Atomic Volume.*

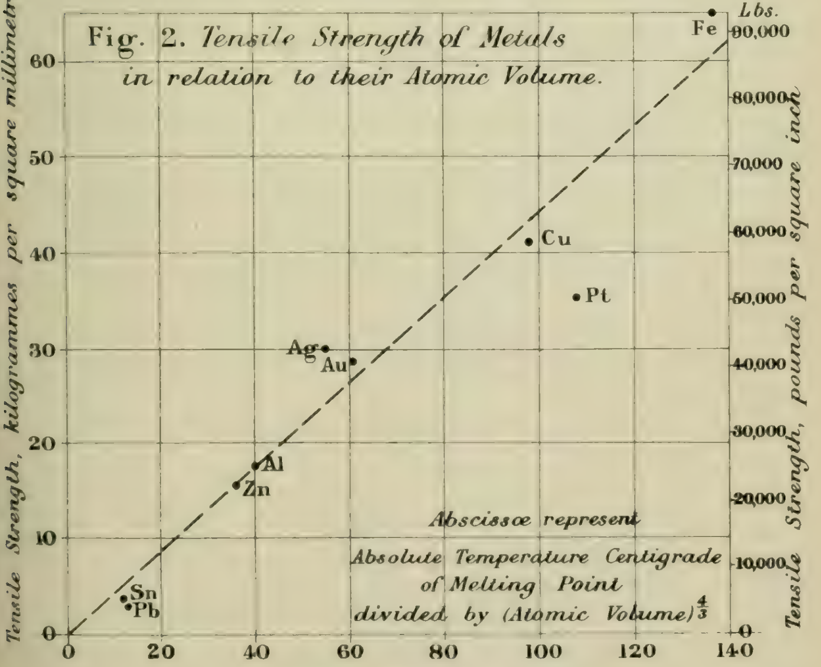
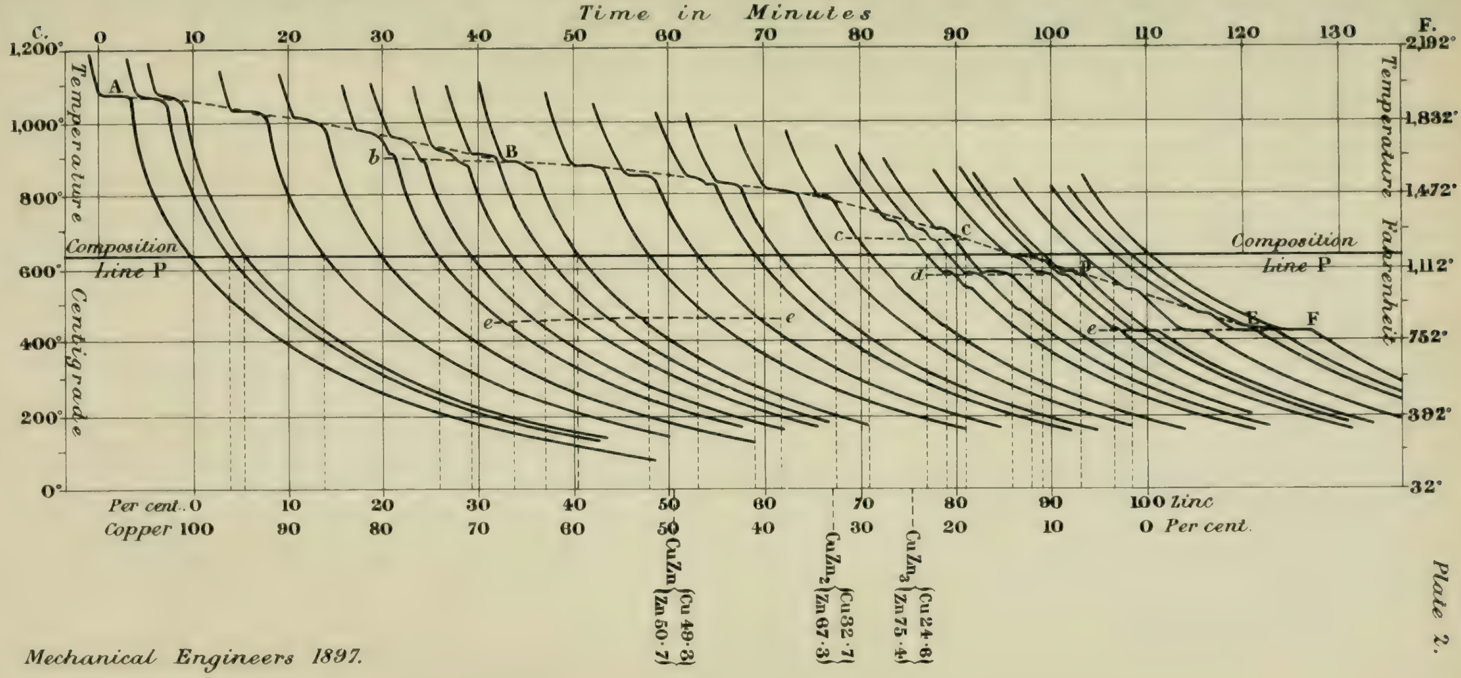


Fig. 2. *Tensile Strength of Metals in relation to their Atomic Volume.*

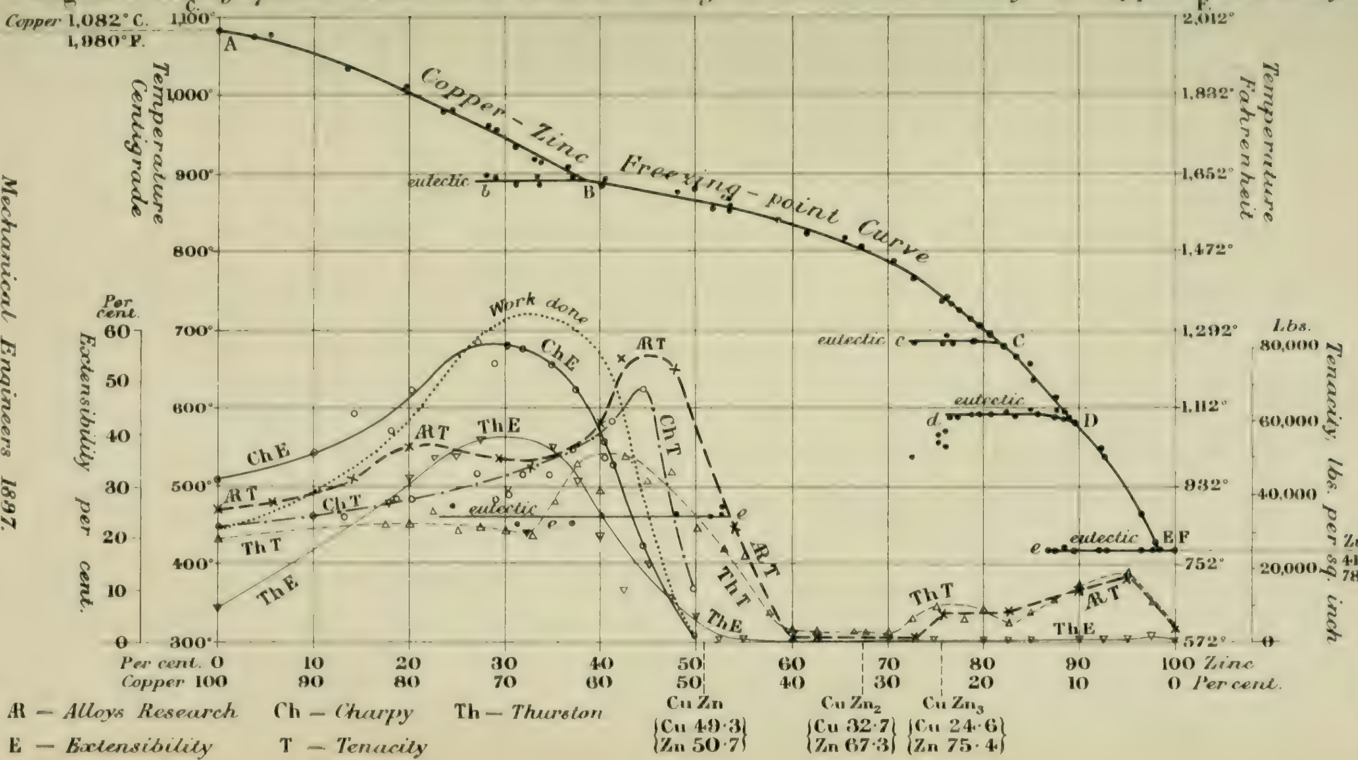
ALLOYS RESEARCH.

Fig. 3. *Cooling Curves of Copper-Zinc Alloys.*



Mechanical Engineers 1897.

Fig. 4. *Freezing-point Curve and Tensile Strength and Extensibility of Copper-Zinc Alloys.*



ALLOYS RESEARCH.

Fig. 5.

Freezing-point Curve and Tensile Strength and Extensibility of Lead-Tin Alloys.

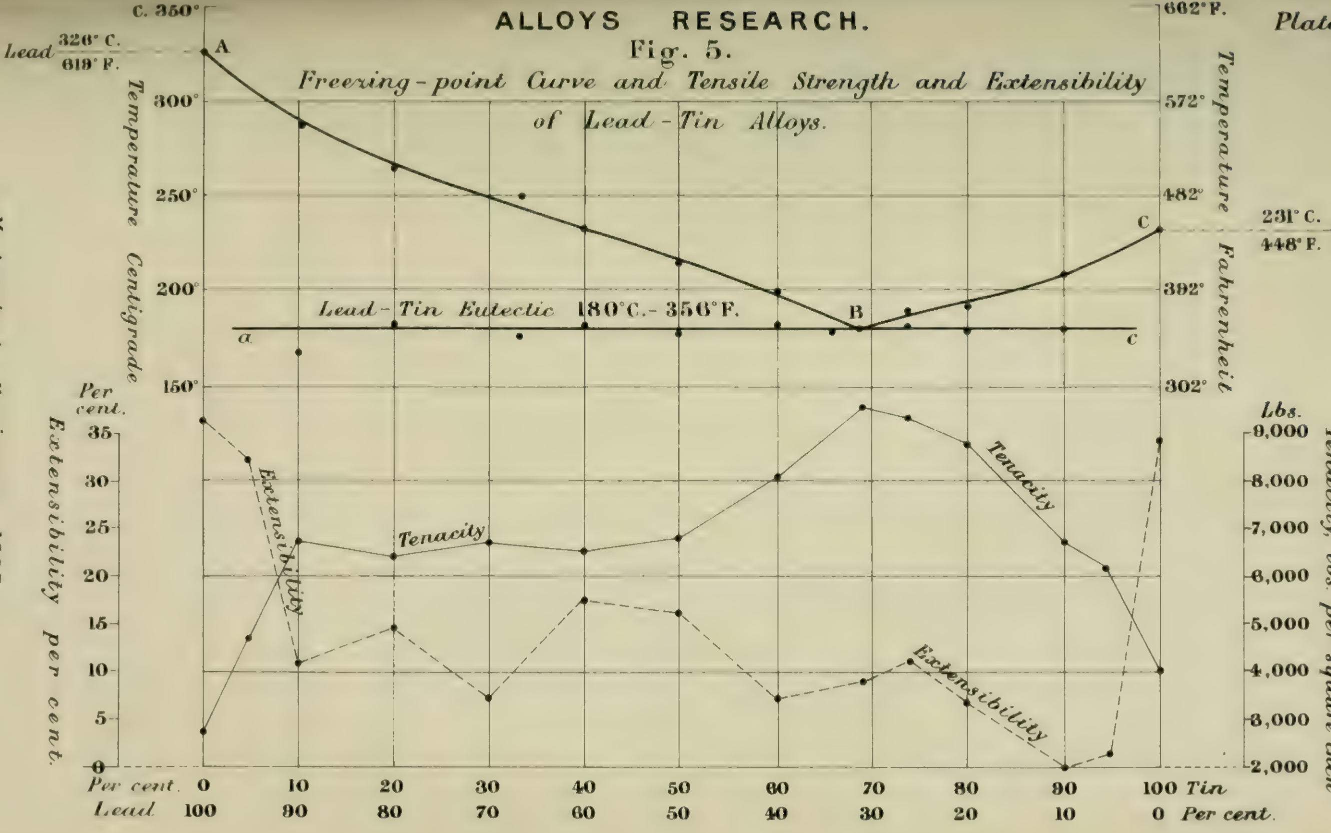


Plate 4.

ALLOYS RESEARCH.

Fig. 6.

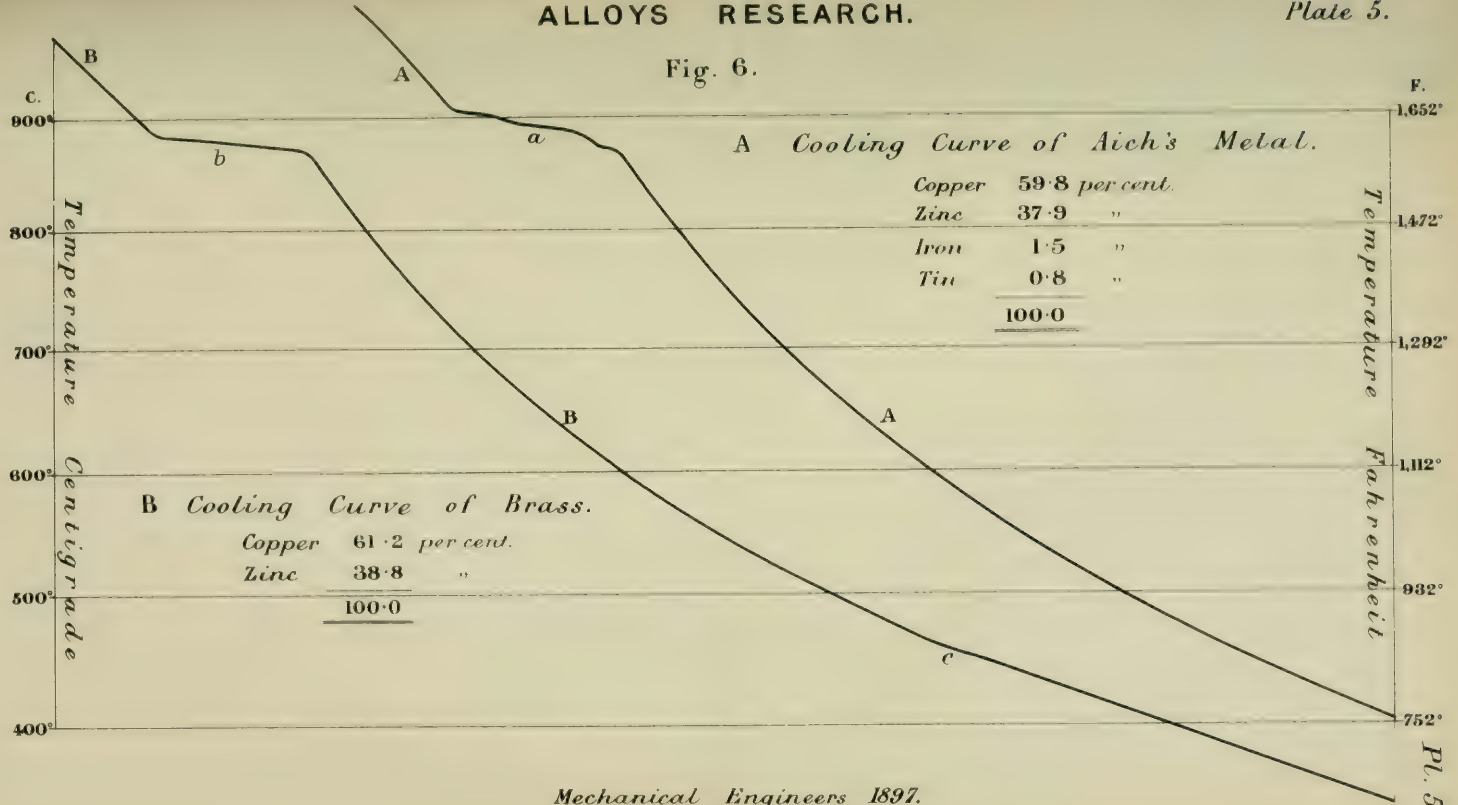


Fig. 7. *Squeezer. Half full size.*

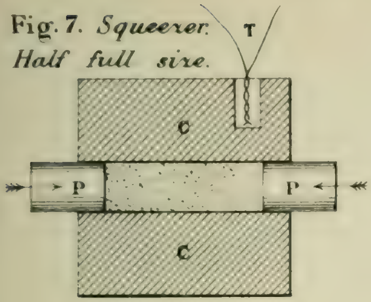


Fig. 8.

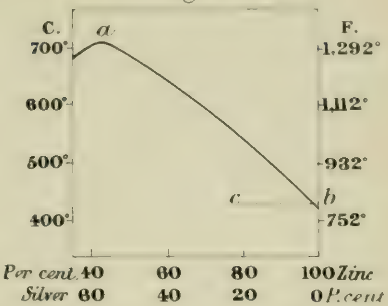


Fig. 10.

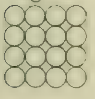


Fig. 11. *Polarised.*

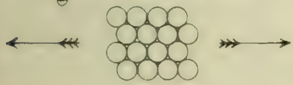


Fig. 9.

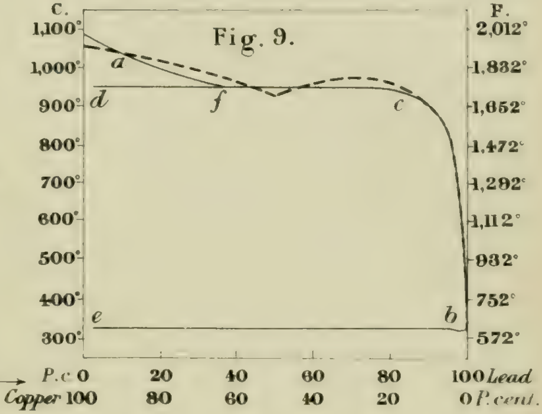
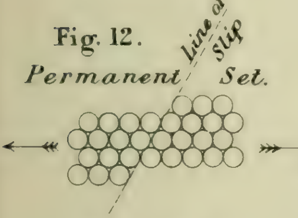


Fig. 12. *Permanent Set.*



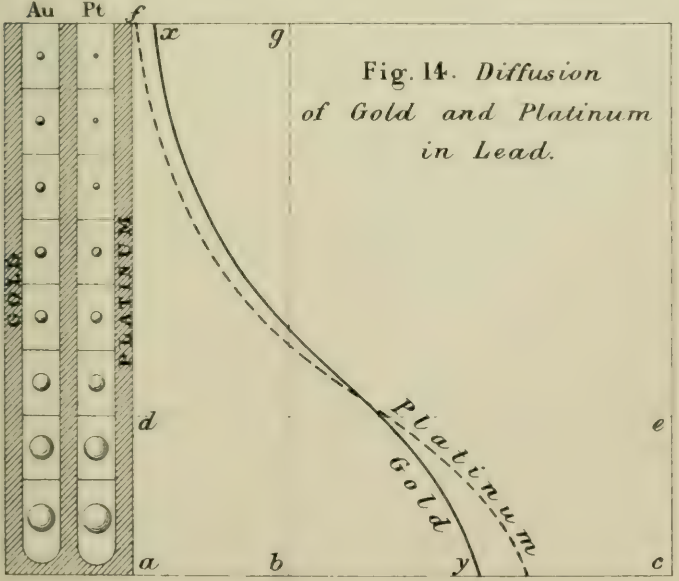


Fig. 14. *Diffusion of Gold and Platinum in Lead.*

ALLOYS RESEARCH.

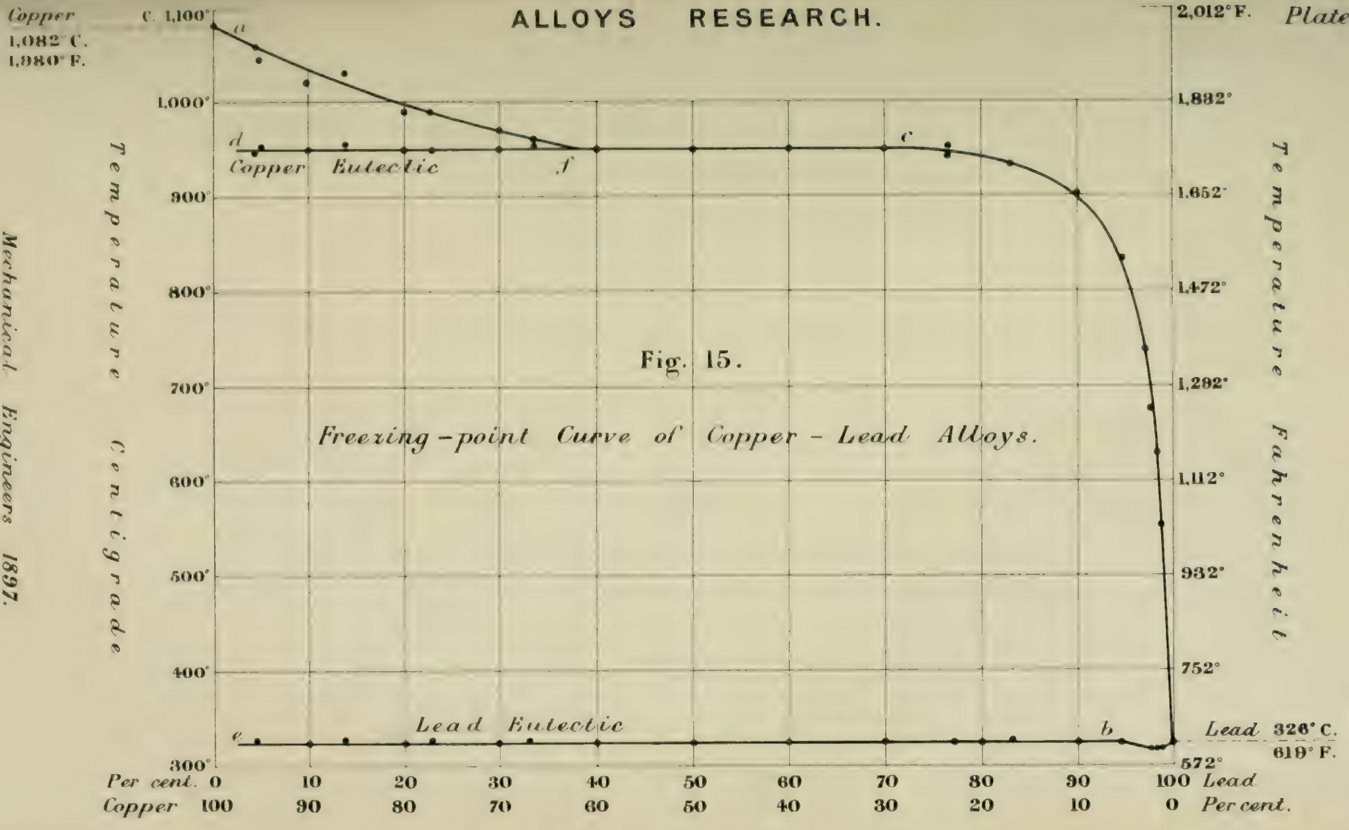
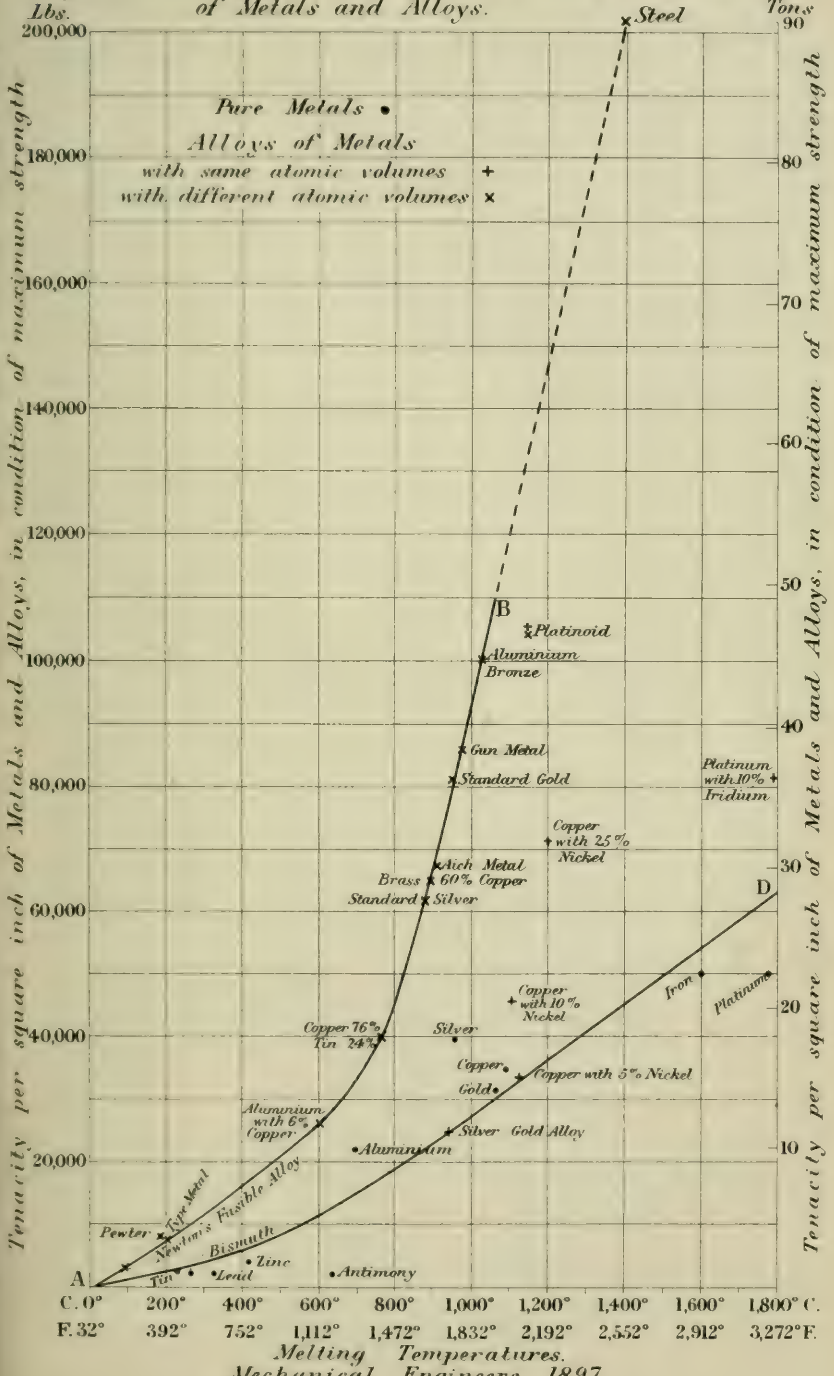


Fig. 15.

Freezing-point Curve of Copper-Lead Alloys.

Fig 16. *Relation between Tenacity and Melting Temperatures of Metals and Alloys.*



Mechanical Engineers 1897.

Fig. 17. *Freezing of Tin.*

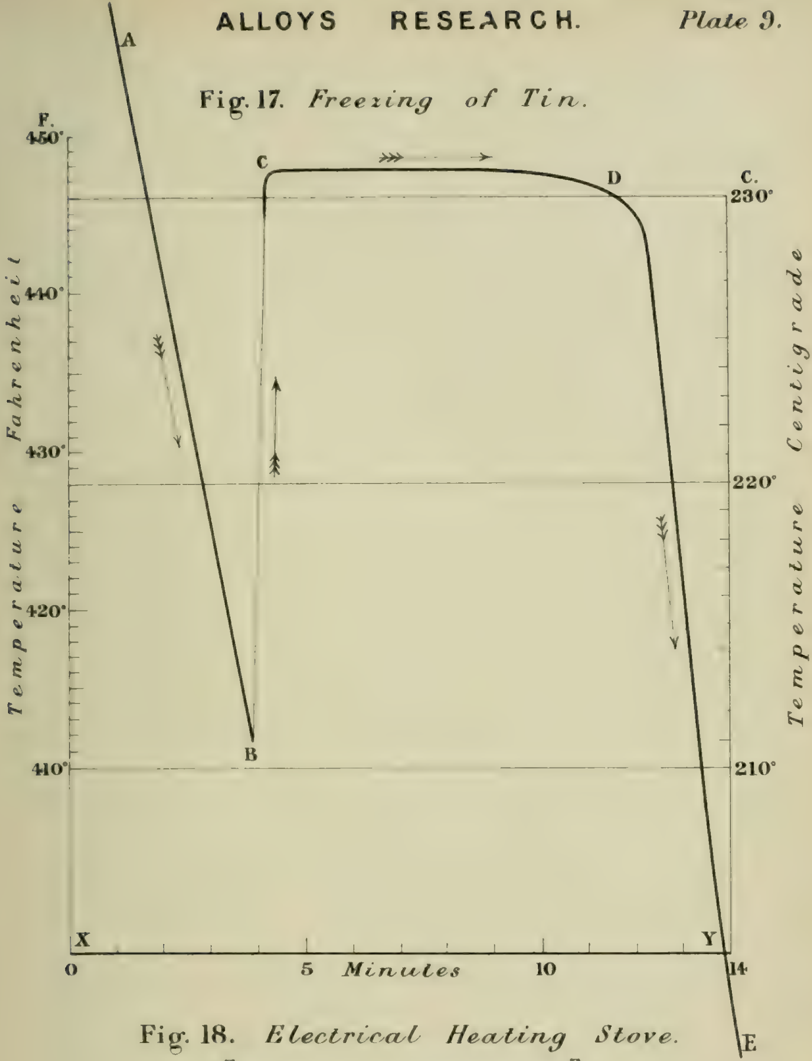
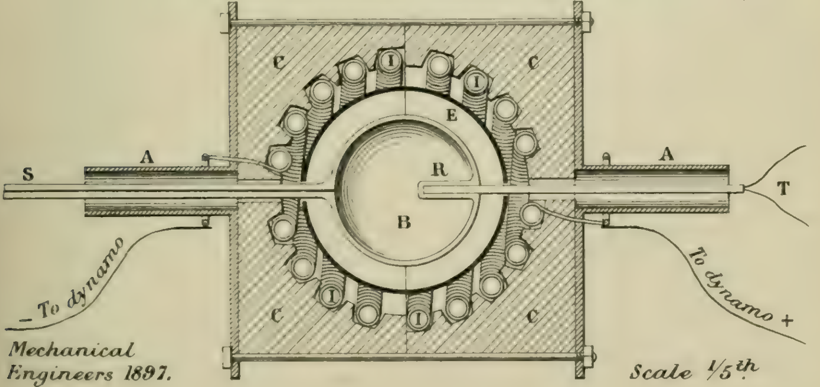


Fig. 18. *Electrical Heating Stove.*



Scale 1/5th.

Fig. 19. *Freezing-point Curves of Copper-Tin Alloys; corrected from Plates 41-43 of 1895.*

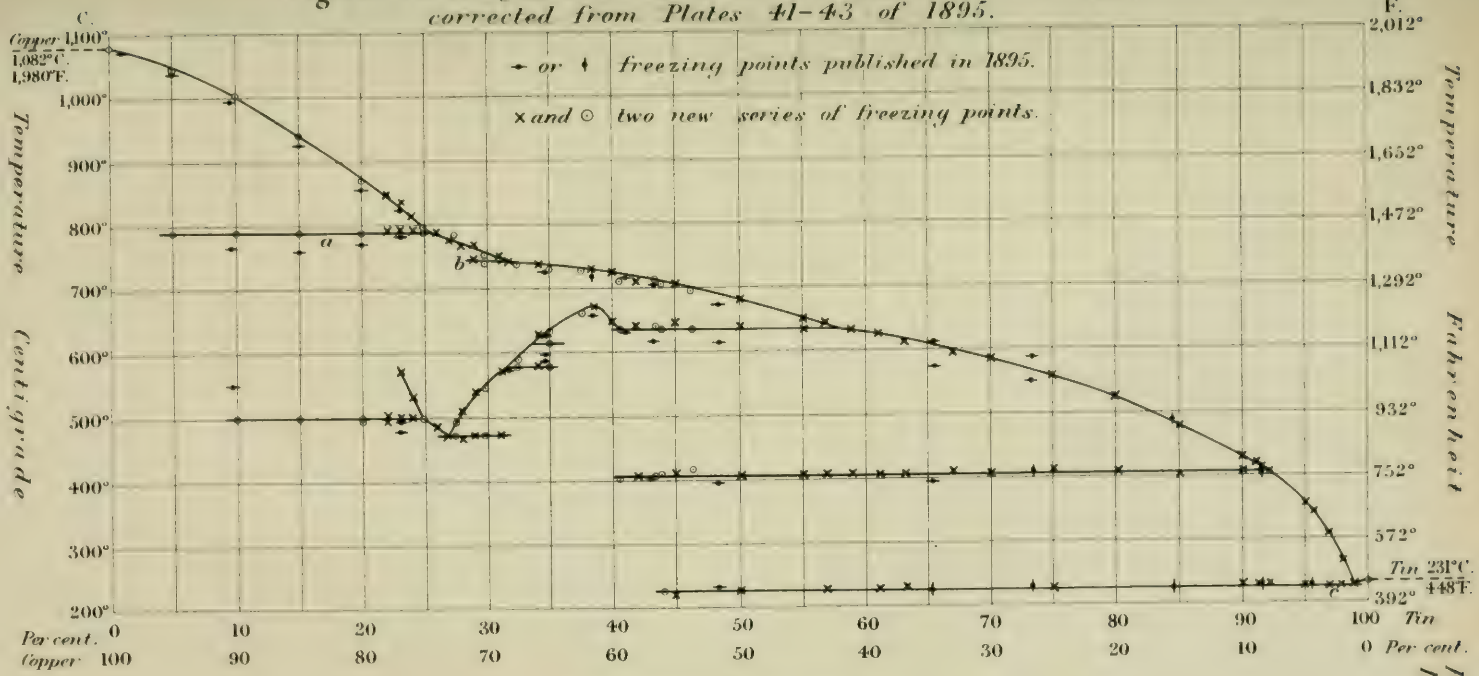
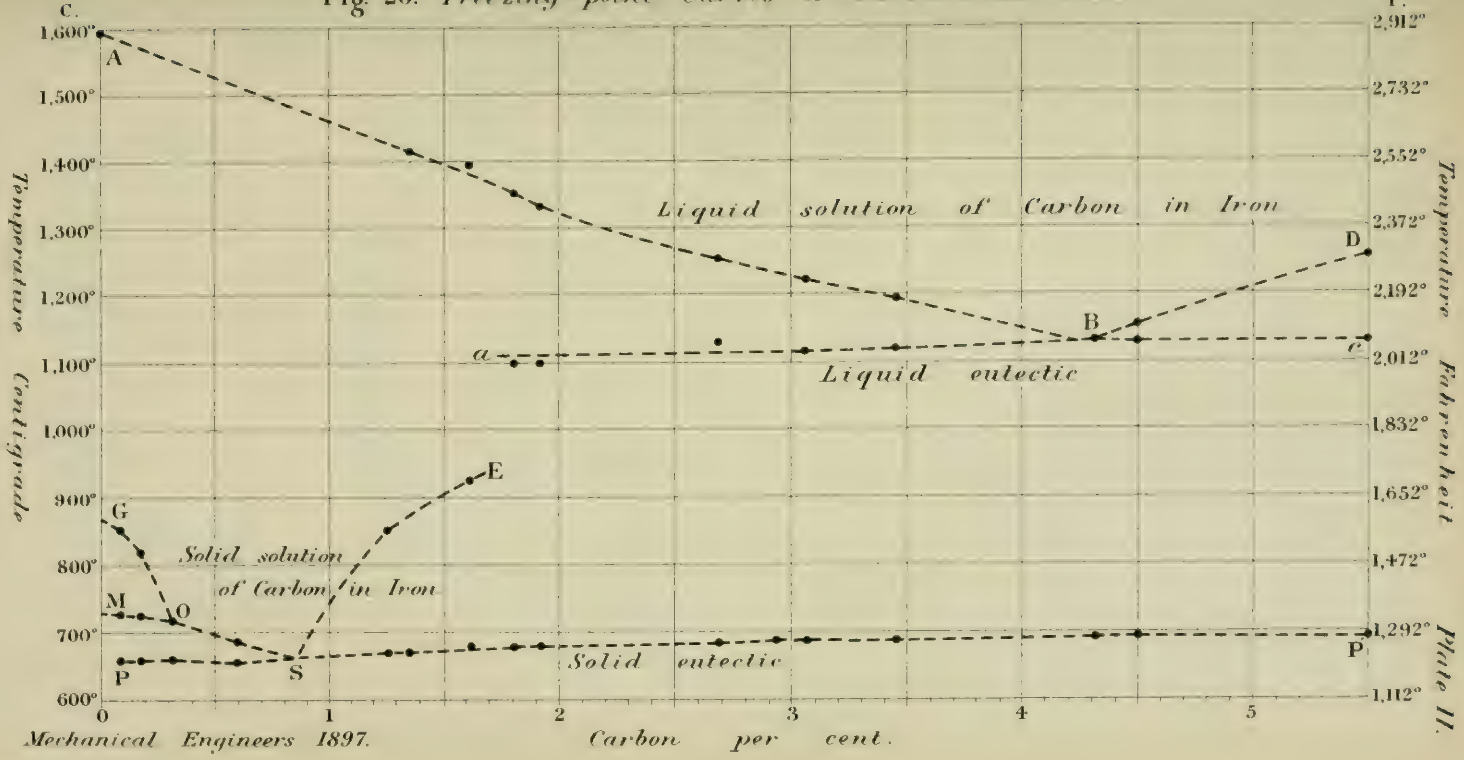


Fig: 20. *Freezing-point Curves of Carburized Iron.*



Mechanical Engineers 1897.

Brass Cartridge-Case for 6-inch quick-firing Gun.

Fig. 21. *Blank Disc punched out of sheet metal.*

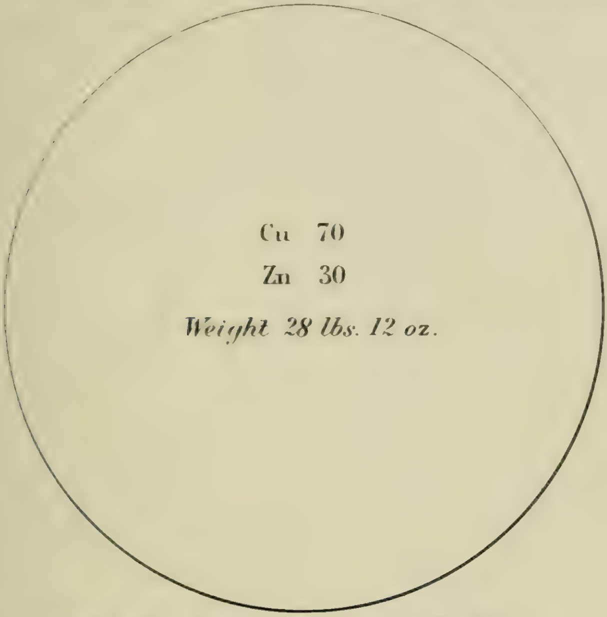


Fig. 22. *Edge view of Disc.*

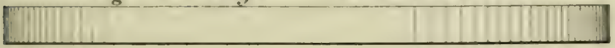


Fig. 23. *Cup formed in hydraulic press, followed by annealing.*

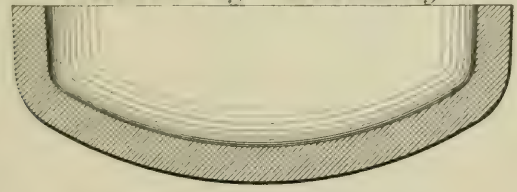
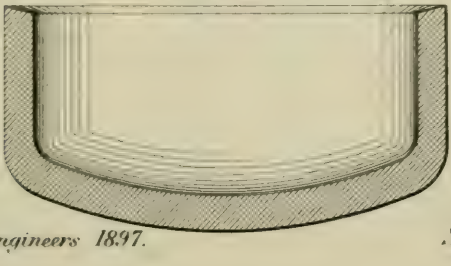


Fig. 24. *First Draw, followed by annealing.*



Scale 1/4th.

Brass Cartridge-Case for 6-inch quick-firing Gun.

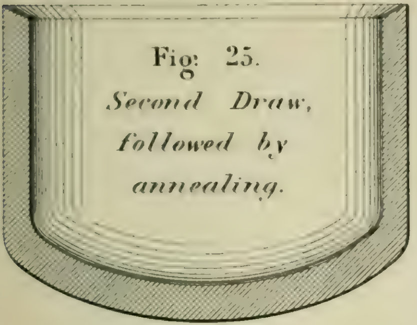


Fig: 25. *Second Draw, followed by annealing.*

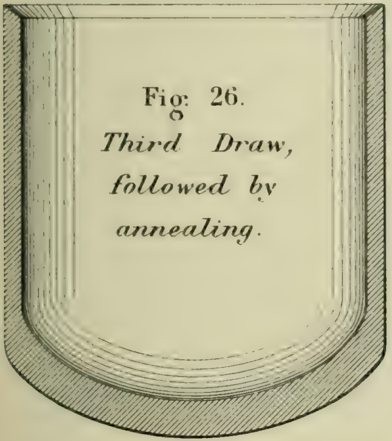


Fig: 26. *Third Draw, followed by annealing.*

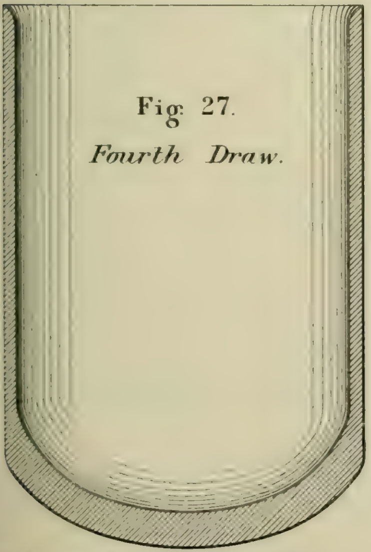


Fig: 27. *Fourth Draw.*

Fig: 28. *First Indent of base or head, followed by annealing.*

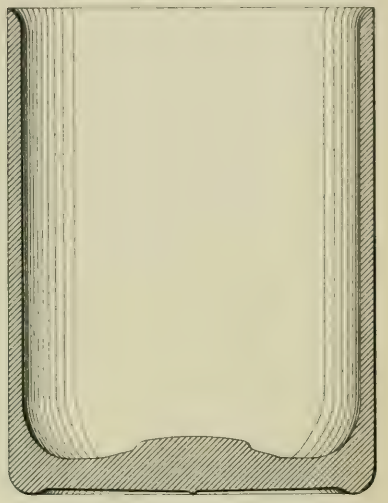
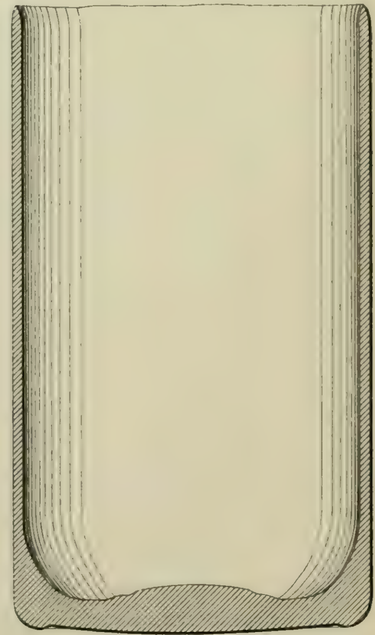


Fig: 29. *Fifth Draw, followed by annealing.*



Scale 1/4 th

Brass Cartridge-Case for 6-inch quick-firing Gun.

Fig. 30.

Sixth Draw,
followed by
annealing.

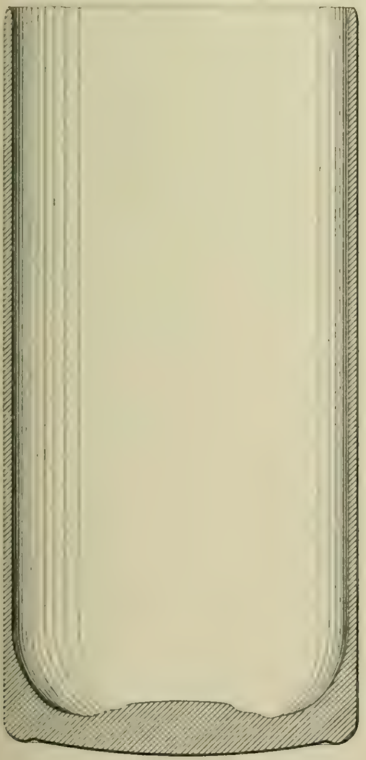
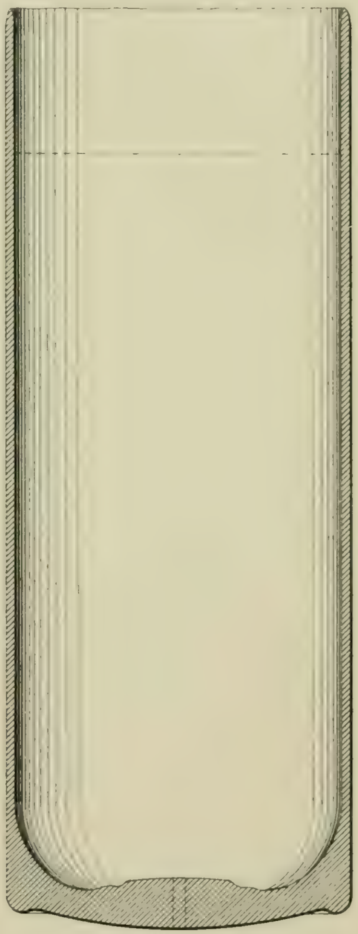


Fig. 31.

Seventh Draw,
followed by
first trimming of mouth,
and drilling air hole in head.



Scale 1/4th.

Brass Cartridge-Case for 6-inch quick-firing Gun.

Fig. 32.
*Second Indent
of base or head,
followed by
final annealing.*

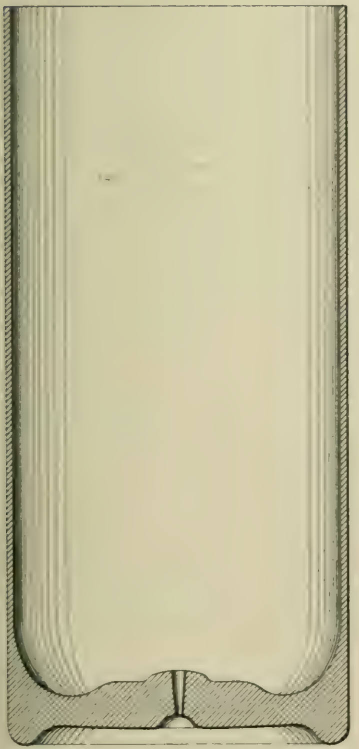
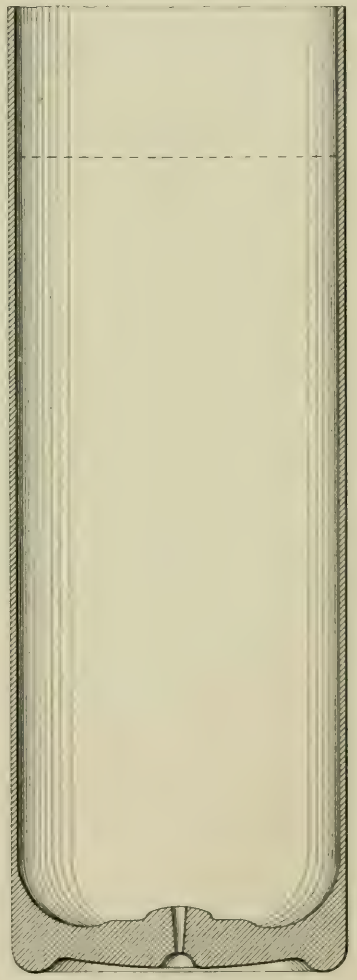


Fig. 33.
*Eighth Draw,
followed by
second trimming of mouth.*



Scale 1/4th

Brass Cartridge-Case for 6-inch quick-firing Gun.

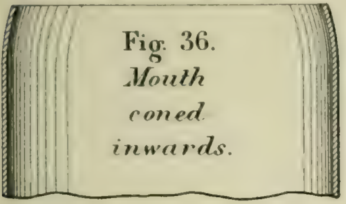


Fig. 36. *Mouth coned inwards.*

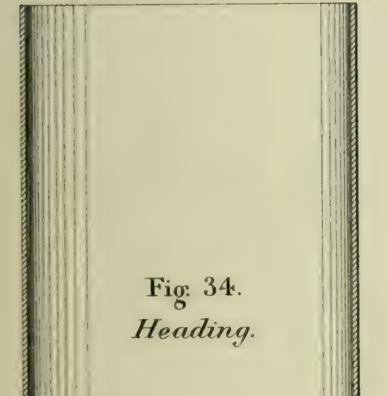


Fig. 34. *Heading.*

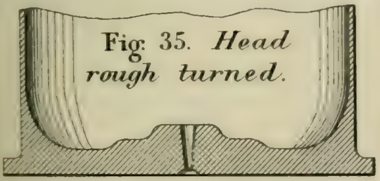


Fig. 35. *Head rough turned.*

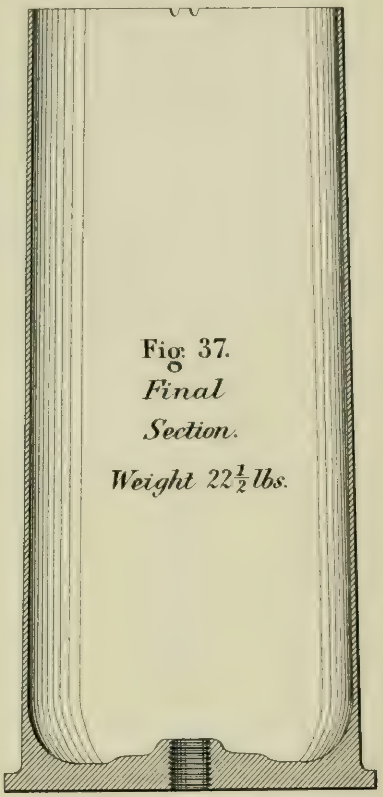


Fig. 37. *Final Section.*

Weight 22½ lbs.

Fig. 38. *Rear end.*

Scale ¼th

SECTION OF WATERWAY. *Plate 17.*

Plate 17.

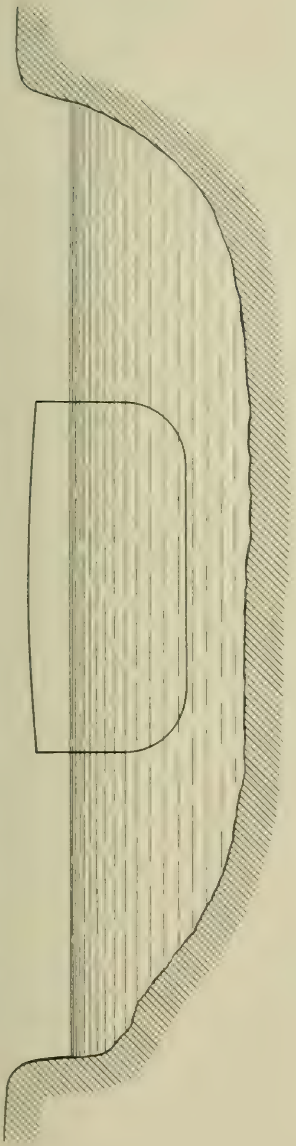


Fig. 1. *Average depth* 5·98 *feet. Area* 239·2 *square feet.*

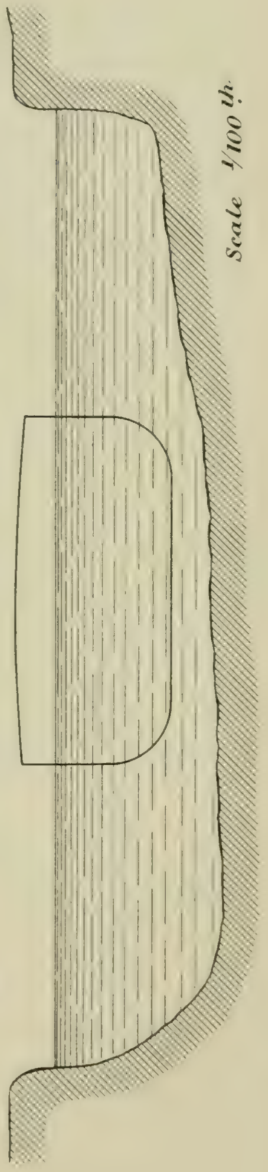


Fig. 2. *Average depth* 5·62 *feet. Area* 224·8 *square feet.*

Scale 1/100*th.*

Plate 18.

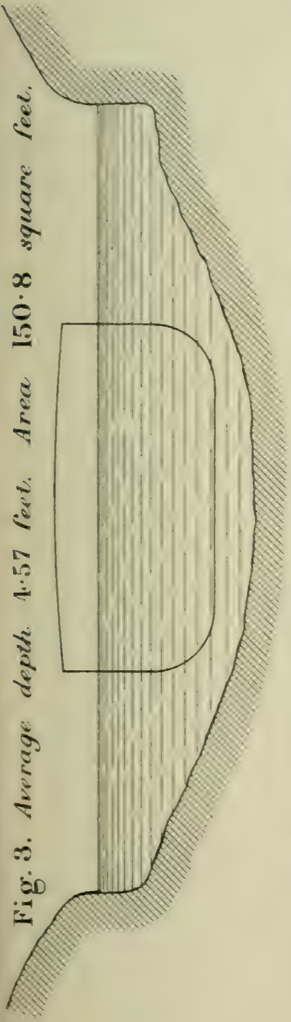


Fig. 3. Average depth 4·57 feet. Area 150·8 square feet.

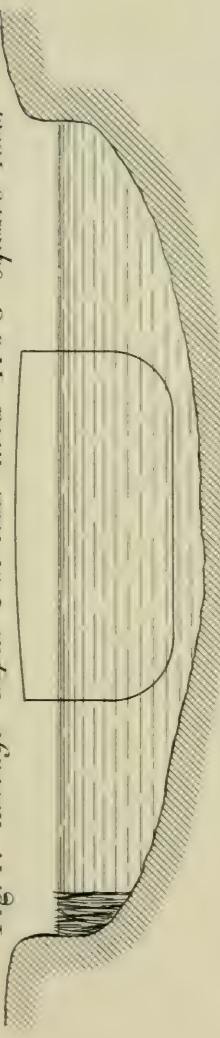


Fig. 4. Average depth 4·31 feet. Area 146·5 square feet.

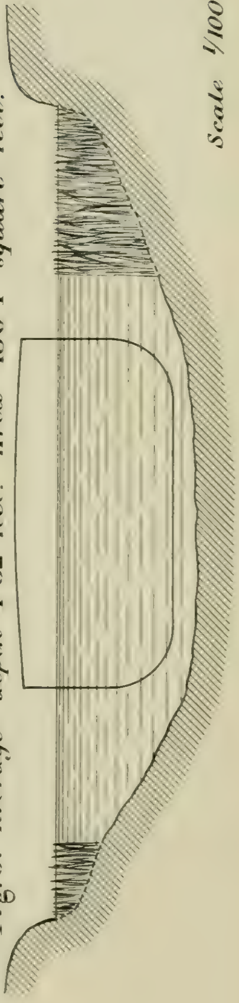


Fig. 5. Average depth 4·82 feet. Area 130·1 square feet.

Scale 1/100th.

Scale 1/100th

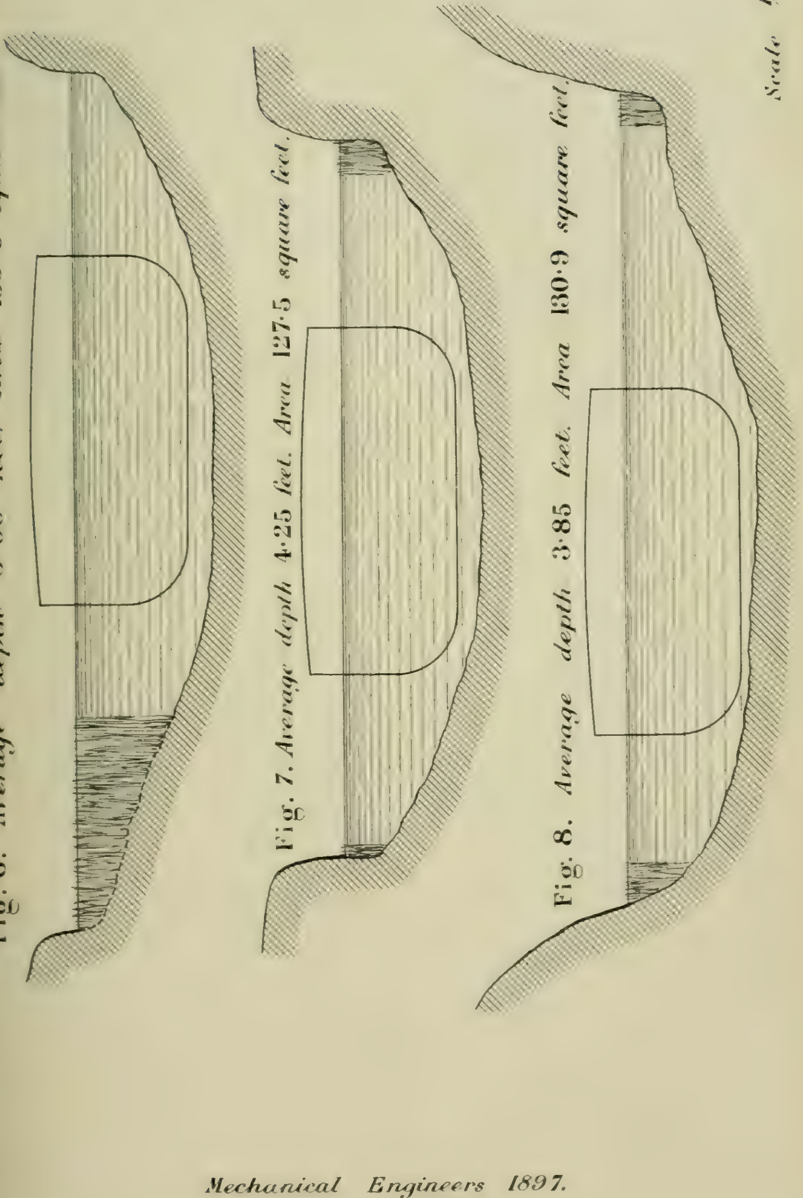


Fig. 6. *Average depth 3·99 feet. Area 153·6 square feet.*

Fig. 7. *Average depth 4·25 feet. Area 127·5 square feet.*

Fig. 8. *Average depth 3·85 feet. Area 130·9 square feet.*

SECTION OF WATERWAY.

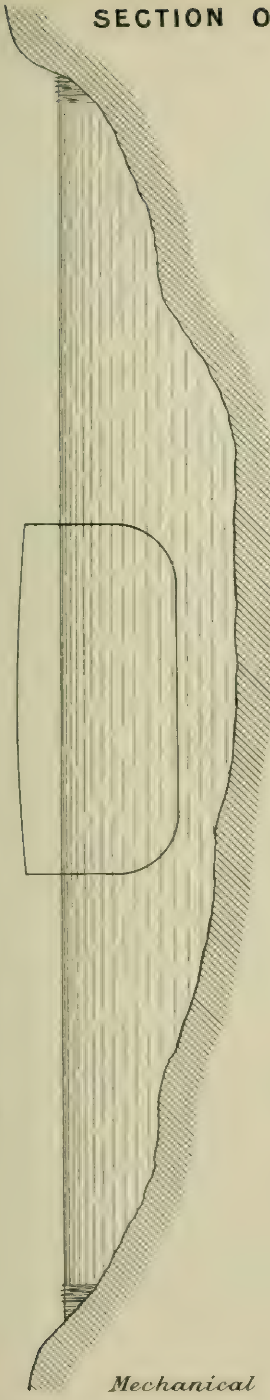


Fig. 9. *Average depth* 4·94 *feet. Area* 256·9 *square feet.*

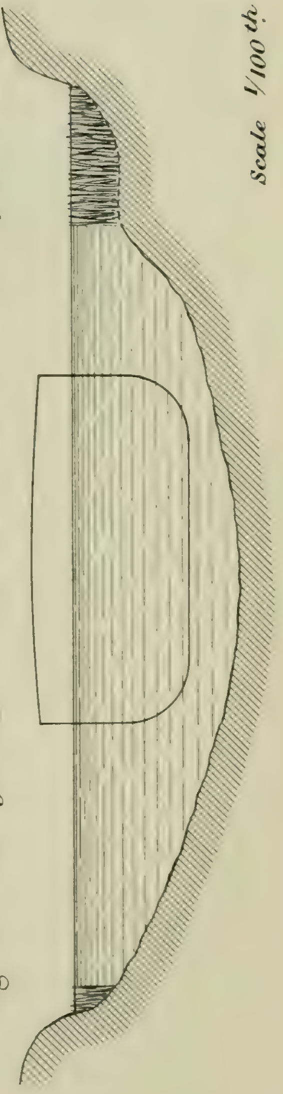


Fig. 10. *Average depth* 4·15 *feet. Area* 153·5 *square feet.*

Scale $1/100$ *th.*

Fig. 11. *Steam Lighter " Tyrone."*

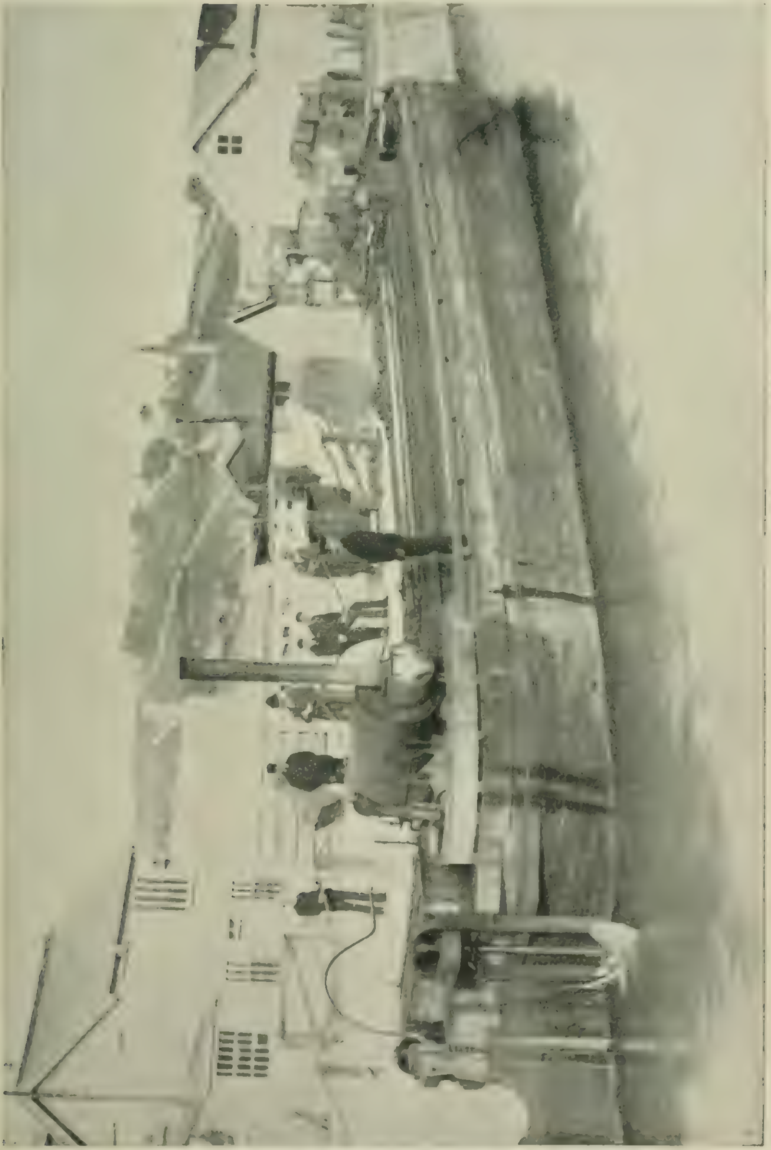


Fig. 12. "*Pioneer.*"

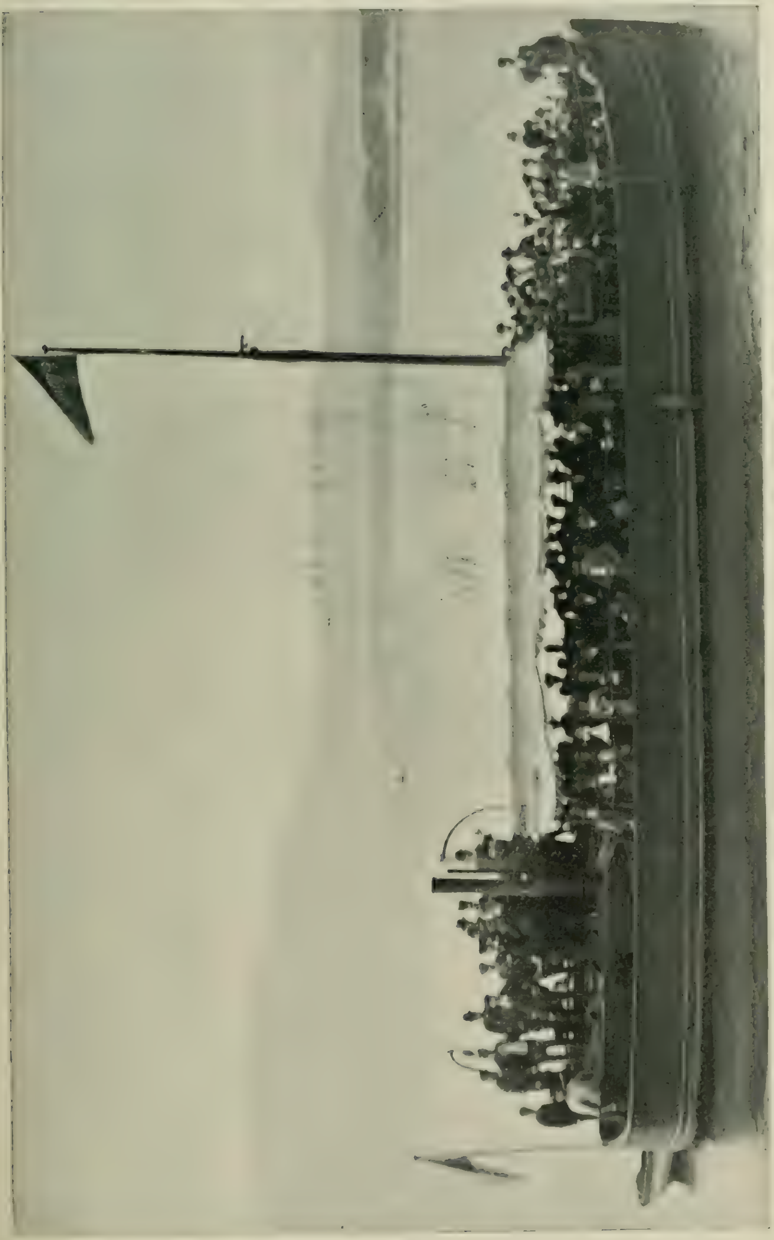
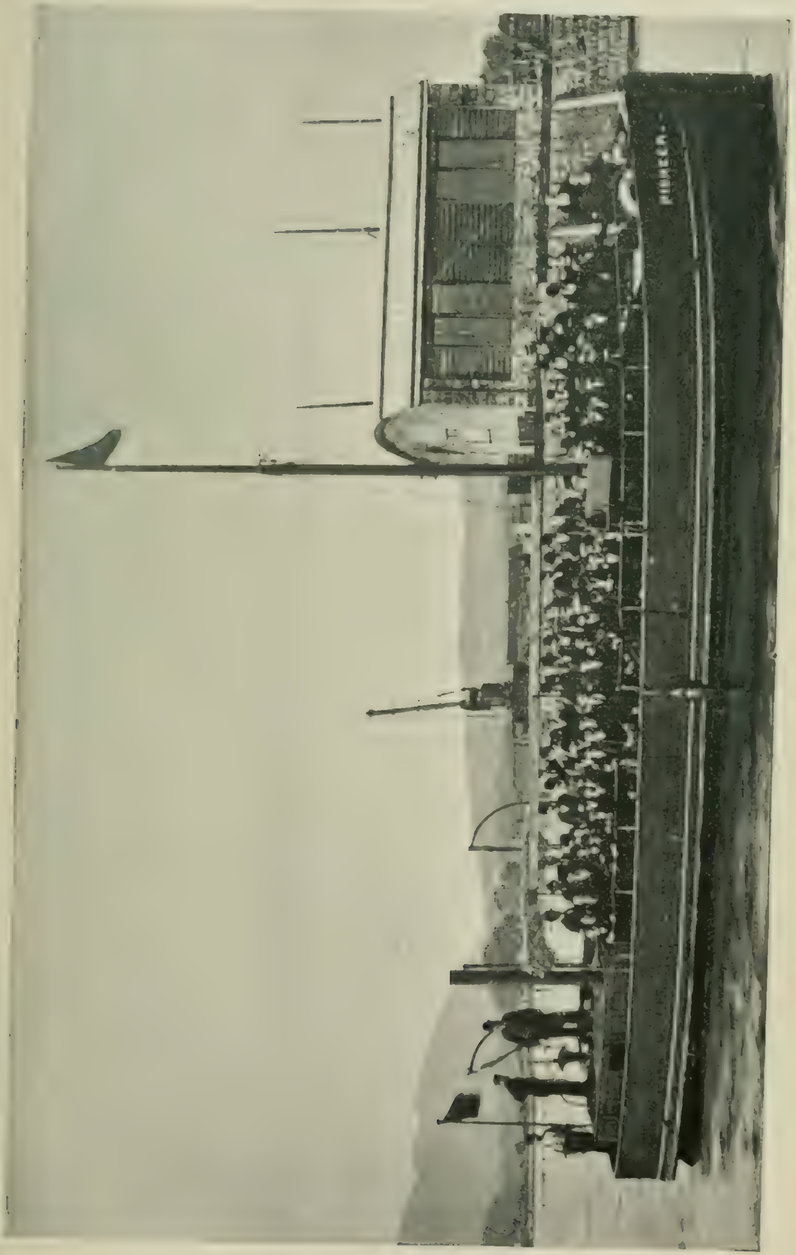


Fig. 13. "*Pioneer.*"



Models of Propellers and Frames.

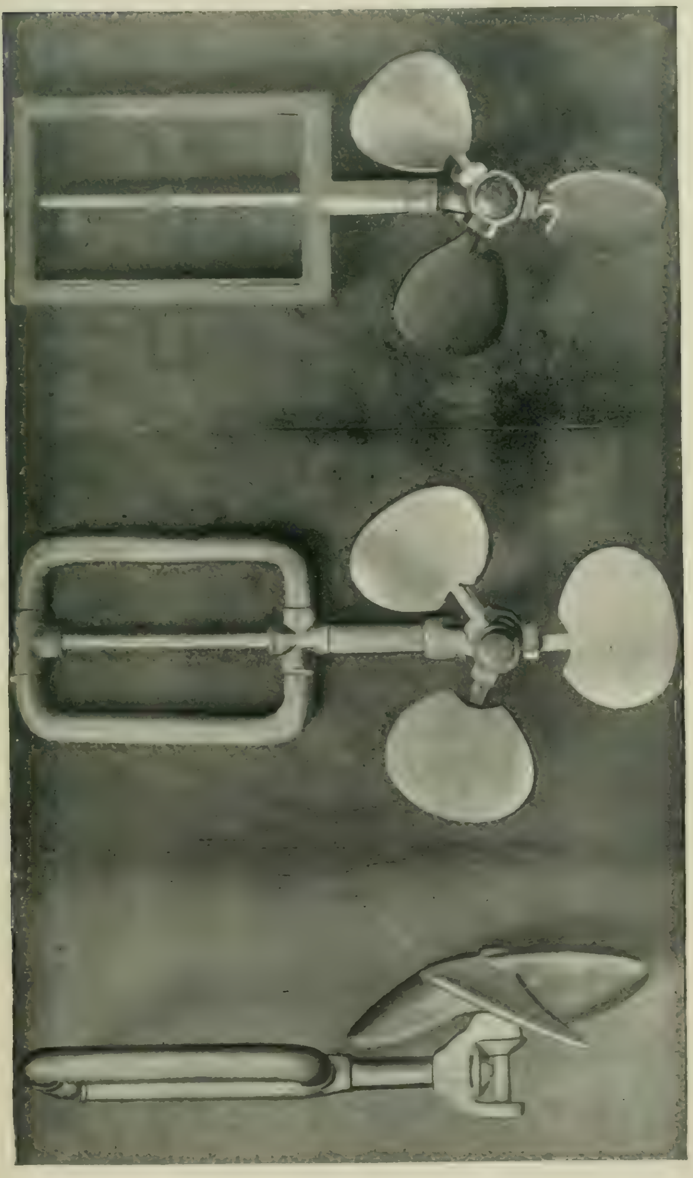


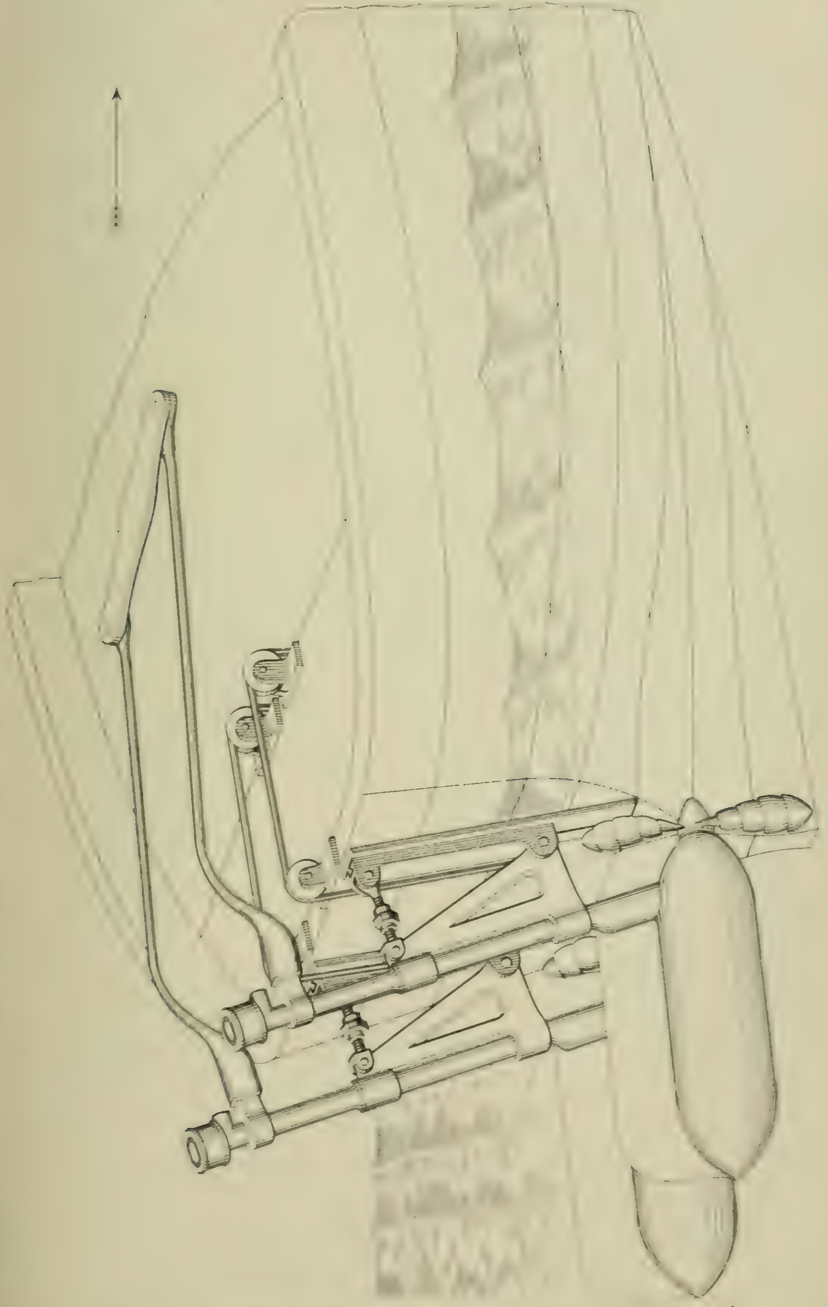
Fig. 16.

Fig. 15.

Fig. 14.

Electric Rudder-Motor.

Fig. 17. *Stern view of Boat.*



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Electric Rudder-Motor.

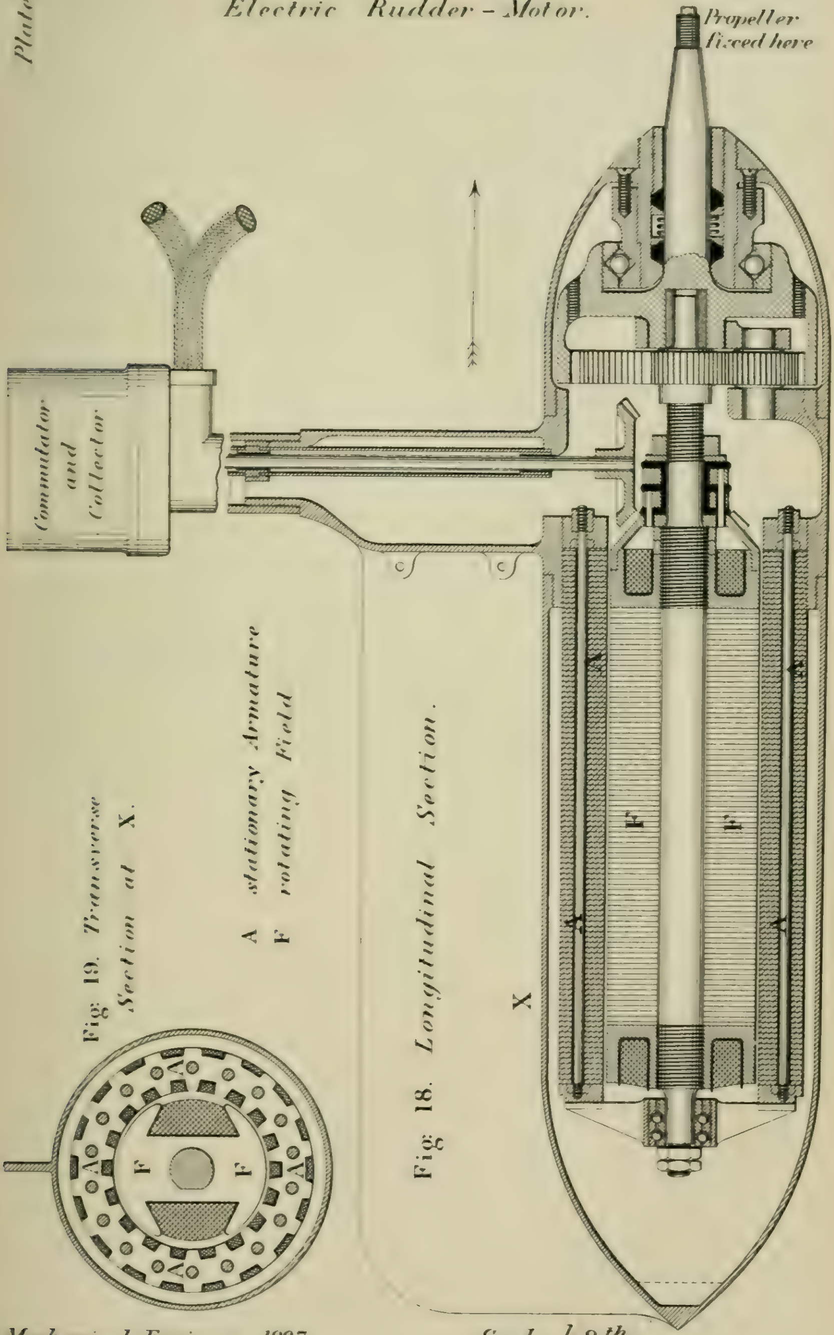


Fig. 19. Transverse Section at X.

A stationary Armature
F rotating Field

Fig. 18. Longitudinal Section.

Mechanical Engineers 1897.

Scale 1/8th

0 5 10 15 20 Inches 25

Fig. 21.

Resistance independent of Length of boat.

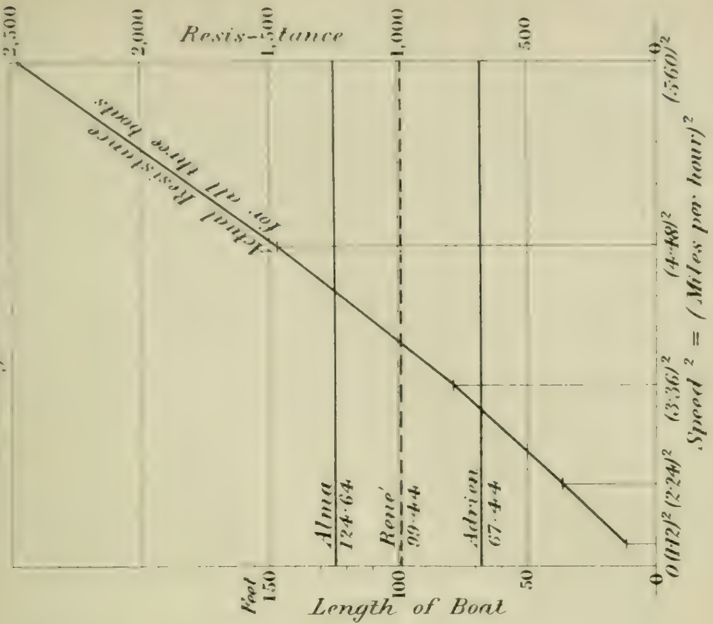
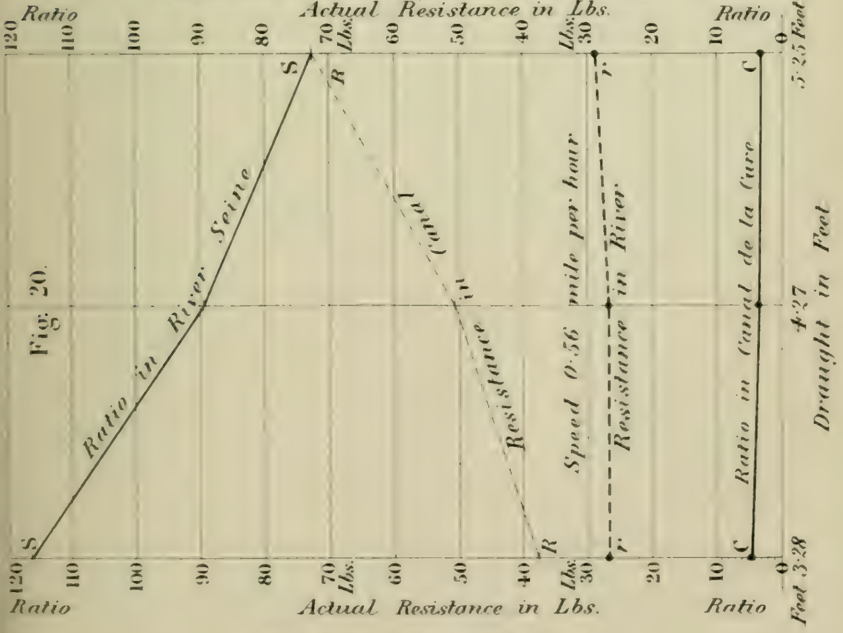


Fig. 20. *Ratio of wetted section of Waterway to immersed midship section of Boat, and Resistance to traction, in Canal and in River, with different Draughts of same boat.*



The Institution of Mechanical Engineers.

PROCEEDINGS.

April 1897.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 28th April 1897, at Half-past Seven o'clock p.m.; E. Windsor Richards, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following fifty-one candidates were found to be duly elected:—

MEMBERS.

Avery, William Beilby,	Birmingham.
Bell, Capt. Charles Thornhill, R.A.,	Madras.
Bellamy, Alfred Rowe,	Stockport.
Bright, Charles, F.R.S.E.,	London.
Brodrick, William Holborn,	Hull.
Brooks, Samuel Herbert,	Manchester.
Fisher, Pearson,	Amsterdam.
Haldane, John Wilton Cuninghame,	Liverpool.
Meredith, John,	Nottingham.
Penn, Frederick James,	Birmingham.
Robinson, Charles Arthur,	Plymouth.
Shepherd, John Lupton,	Leeds.
Smith, Robert Walker,	Redditch.

Snoxell, George Edgar,	Dursley.
Stagg, William,	Bristol.
Steele, James,	Wishaw.
Wicksteed, Charles,	Kettering.
Wright, Frederick George,	Swindon.

ASSOCIATE MEMBERS.

Back, Arthur Charles Lemprière,	Dartford.
Beck, John,	Gosport.
Clegg, John Henry,	Manchester.
Davy, David, Jun.,	Sheffield.
Furness, Charles,	Sheffield.
Halsey, Charles Turner,	London.
Harlow, Bernhard Schäffer,	Stockport.
Hawes, William Fox, Jun.,	London.
Hawkins, Thomas Spear,	Morro Velho.
Hemingway, Alfred,	Albany.
Hodges, Frank William,	Cairo.
Ironside, William Allan,	London.
Lacy-Hulbert, Charles Edward,	Brussels.
Leitch, Archibald,	Glasgow.
Meggitt, George Teale,	Sutton-in-Ashfield.
Page, Henry,	Nottingham.
Richmond, William Frederick,	Langley Mill.
Roylance, Arthur Herbert,	Manchester.
Sanders, George,	Wolverhampton.
Sime, William,	London.
Spence, John C.,	Johannesburg.
Suffield, Frank Wilson,	Birmingham.

ASSOCIATES.

Kenway, William Edward,	Birmingham.
Starley, William,	Coventry.
Wood, William Alfred,	Manchester.

GRADUATES.

Bartley, Bryan Cole,	Barrow-in-Furness.
Bowden, John Horace,	Manchester.

EMERY, JAMES INMAN,	Madras.
ETLINGER, GEORGE ERNEST,	Crewe.
MUGGERIDGE, HAROLD CHISMAN,	Burton-on-Trent.
OSWALD, GEORGE HERBERT,	London.
WILLIAMS, HAL,	London.
WILSON, ROBERT JAMES,	London.

The PRESIDENT announced that for the forthcoming Jubilee Meeting in Birmingham, the birthplace of the Institution, the local Members, under the chairmanship of Mr. Arthur Keen, Member of Council, were doing all they could to arrange a reception worthy of the city and of the Institution. The Members he trusted would show by attending the meeting their appreciation of the arrangements, and their pride in belonging to an Institution which had arrived at the age of fifty years, and was now in the enjoyment of fuller vigour than ever before.

The Institution House was already making good progress, and the Members would shortly be invited to take up 250 debentures of £100 each, for facilitating its completion. The whole of these debentures the Council would much prefer should be taken up by the members; and also that they should be taken up by 250 members, rather than be absorbed by a few. The applications would be dealt with in order of priority, as far as consistent with the latter suggestion. The rate of interest would be four per cent.

The following Paper was then read and partly discussed:—

"Mechanical Propulsion on Canals"; by Mr. LESLIE S. ROBINSON, of London.

At Ten o'clock the Meeting was adjourned to Friday evening. The attendance was 63 Members and 40 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Friday, 30th April 1897, at Half-past Seven o'clock p.m.; E. WINDSOR RICHARDS, Esq., President, in the chair.

The Discussion upon Mr. Robinson's Paper upon Mechanical Propulsion on Canals was resumed and concluded; and the following Paper was read and partly discussed:—

"Experiments on Propeller Ventilating Fans, and on the Electric Motor driving them"; by Mr. WILLIAM GEORGE WALKER, of London.

At Ten o'clock the Discussion was adjourned to the Autumn Meeting of the Institution.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in allowing the use of their rooms for the Meeting of this Institution.

The Meeting then terminated. The attendance was 50 Members and 70 Visitors.

The JUBILEE DINNER of the Institution was held at the Hotel Cecil, Strand, on Thursday evening, 29th April 1897, and was very largely attended by the Members and their friends, the company numbering upwards of 350. The President occupied the chair; and the Dinner was honoured by the presence of Field Marshal His Royal Highness the Duke of Cambridge, K.G., K.T., K.P., Honorary Member of the Institution. The following guests also accepted the invitations sent to them, though those marked with an asterisk * were unavoidably prevented at the last from being present. The Right Hon. the Lord Mayor of Belfast, Alderman W. J. Pirrie; the Right Hon. Lord Medway; Sir Frederick A. Abel, Bart., K.C.B., D.C.L., D.Sc., F.R.S., Honorary Life Member; Sir Albert K. Rollit,* LL.D., M.P., President of the

London Chamber of Commerce; Vice-Admiral P. H. Colomb; Lieut.-General B. Bateson; Mr. Laurence Hardy, M.P.; Alderman W. Vaughan Morgan*; Professor W. Cawthorne Unwin, F.R.S., Honorary Life Member; Professor D. E. Hughes, F.R.S.

Mr. J. Wolfe Barry, C.B., F.R.S., President of the Institution of Civil Engineers; Mr. George May,* President of the North of England Institute of Mining and Mechanical Engineers; Mr. Joseph Nasmith, President of the Manchester Association of Engineers; Mr. Henry W. Martin,* President of the South Wales Institute of Engineers; Mr. Daniel Watney, President of the Surveyors' Institution; Mr. Tom Westgarth,* President of the Cleveland Institution of Engineers; Sir Henry Mance, C.I.E., President of the Institution of Electrical Engineers; Mr. W. Lloyd Wise, President of the Chartered Institute of Patent Agents; Mr. Henry F. Swan,* President of the North-East Coast Institution of Engineers and Shipbuilders; Mr. Alexander R. Binnie,* President of the Institution of Junior Engineers; Mr. R. Pawley, President of the Hull and District Institution of Engineers and Naval Architects; Mr. J. Fortescue Flannery, M.P., President of the Institute of Marine Engineers; Mr. James Mactear, F.R.S.E., President of the Institution of Mining and Metallurgy; Mr. Julian C. Rogers,* Secretary of the Surveyors' Institution.

Mr. Bowman Malcolm and Mr. A. Basil Wilson,* Joint Honorary Secretaries of the Belfast Meeting; Mr. W. Bayley Marshall and Mr. Eric M. Carter, Joint Honorary Secretaries of the Birmingham Meeting; Mr. David Duncan; Mr. Harry Lee Millar,* Treasurer; Mr. Leslie S. Robinson; Mr. W. G. Walker; Mr. Charles J. Wilson, F.I.C.; Mr. William G. R. Bousfield; Mr. William Dunk*; Mr. Basil Slade; Mr. Alfred Stansfield; Mr. William H. Merrett.

The President was supported by the following Officers of the Institution:—*Past-Presidents,* Sir William Anderson,* K.C.B., D.C.L., F.R.S.; Sir Lowthian Bell, Bart., F.R.S.; Sir Frederick Bramwell, Bart., D.C.L., F.R.S.; Sir Edward H. Carbutt, Bart.; Mr. Jeremiah Head; Professor Alexander B. W. Kennedy, LL.D., F.R.S.; Mr. Percy G. B. Westmacott.* *Vice-Presidents,* Sir Douglas Galton,* K.C.B., D.C.L., LL.D., F.R.S.; Mr. Edward P. Martin;

Mr. J. Hartley Wicksteed. *Members of Council*, Mr. John A. F. Aspinall, Mr. Henry Davey, Mr. William Dean, Mr. Bryan Donkin, Mr. Arthur Keen, Mr. William Laird, Mr. John G. Mair-Rumley, Mr. Thomas Mudd,* and Mr. James Platt.

After the usual loyal toasts, the President proposed "Our Guests," which was acknowledged by His Royal Highness the Duke of Cambridge, K.G., K.T., K.P., Honorary Member of the Institution. Sir Frederick Bramwell, Bart., D.C.L., LL.D., F.R.S., Past-President, proposed the toast of "The Navy and the Army," which was acknowledged by Vice-Admiral P. H. Colomb. The toast of "The Houses of Parliament," proposed by the Right Hon. the Lord Mayor of Belfast, Alderman W. J. Pirrie, was acknowledged by Mr. Laurence Hardy, M.P. Professor Alexander B. W. Kennedy, LL.D., F.R.S., Past-President, proposed the toast of "Kindred Societies," which was acknowledged by Mr. J. Wolfe Barry, C.B., F.R.S., President of the Institution of Civil Engineers. The concluding toast of "The Institution of Mechanical Engineers," was proposed by Sir Edward H. Carbutt, Bart., Past-President, and acknowledged by the President.

MECHANICAL PROPULSION ON CANALS.

By Mr. LESLIE S. ROBINSON, of London.

On the occasion of the Belfast Meeting of the Institution last summer an opportunity was afforded to the Members for judging of a plan of Mechanical Propulsion on Canals which has been developed and brought to a practical issue during the past few years. In order that a fuller appreciation may be gained of the difficulties surrounding what might at first sight appear a simple problem, it is thought that a concise review, such as it is the object of the present paper to offer, of the general question of propulsion or haulage on canals, may be of interest. A large amount of the information here compiled, though not original, has hitherto been more or less inaccessible to engineers in this country, not having previously been published in England.

The really complicated subject of traction on canals involves at the outset the determination of the resistance of a boat in a channel of restricted section. This resistance depends in some way upon the ratio $\frac{\Omega}{\omega}$ which the wetted cross section Ω of the canal bears to the immersed midship section ω of the boat. Although this ratio may remain the same, the resistance varies according as the channel becomes shallower and wider, or deeper and narrower; and in a less degree it also varies with the roughness of the channel bed. Again, the form of the boat, while its immersed midship section may remain unchanged, is an important factor in the determination of the resistance: although in a canal the actual form of a boat has not so much influence on the resistance as in open water.

Early investigations.—The laws relating to this subject had been but imperfectly investigated up to the last few years. In the last century Colonel Beaufoy in England, and Du Buat, D'Alembert, Condorcet, and Bossut in France, made some experiments on the resistance of bodies immersed in water, but only on a small scale. In nearly all cases it has been assumed that the resistance R varies with the square of the velocity V, or $R = K \omega V^2$, where K is a coefficient depending on the form of the boat, and ω is the area of its immersed midship section. In the light of subsequent investigations this formula, which was originally due to Du Buat, has been proved to be incorrect. D'Aubuisson derived from it the following formula for the resistance to traction of boats upon a canal of cross section C:— $R = K \frac{\omega V^2}{C + 2 \omega}$. In 1853 M. Comoy made some experiments upon the Canal du Centre, and found that this formula was incorrect. A full account of his experiments, with the resistances to haulage depending upon the ratio of the canal section Ω to the boat section ω, will be found in appendix C to his paper on the "Cost of Traction on the Centre Canal" in the Annales des Ponts et Chaussées for 1855 (third series, vol. 10).

Sweet.—In 1878 some experiments on the resistance to traction of boats were made on the Erie Canal in the United States of America by Elnathan Sweet, Jun. (Transactions of the American Society of Civil Engineers, 1880, vol. ix, pages 99–110), with the object of determining what reduction in the resistance would be produced by deepening the canal one foot. To solve this question it was necessary first to determine the effect produced on traction by the augmentation of the wetted surface of the canal consequent upon increasing the depth one foot. From his results Sweet deduced the following formula for the resistance R in lbs. as a function of the velocity V of the boat in feet per second, and of the ratio n which the wetted section Ω of the canal bears to the immersed midship section ω of the boat, and also of the total wetted surface S of the hull:— $R = \frac{0{\cdot}10303\, S V^2}{n - 0{\cdot}597}$. This formula was not intended to have the general character which has sometimes been attributed to it, but which its author himself was far from claiming. Indeed, as pointed out by M. de Mas, on the one hand for values of the ratio n equal to and even less than unity it gives finite results;

and on the other, when n tends towards infinity, the resistance tends towards zero. But as a matter of fact, as soon as n equals unity the resistance becomes infinite, and when n tends towards infinity the resistance tends towards a value which is the resistance of the boat in open smooth water.

De Mas.—The most exhaustive and important experiments that have yet been made upon the resistance to traction on canals were commenced in 1890 by M. de Mas with the chief kinds of boats in general use upon the canals in the North of France; and his first experiments were made upon the river Seine, with a view to determining the resistance of the boats in an expanse of smooth water. The wetted section of the Seine above the weir of Port-à-l'Anglais, where the experiments were made, is at least 5,651 square feet, while the boats tried were about 16·4 feet wide and immersed 6·2 feet deep, that is about 102 square feet of immersed section: so that the ratio n of the sections $= \frac{\Omega}{\omega} = \frac{5,651}{102} = 55 \cdot 4$; and therefore the results may be taken as if the boats had been tried in an unlimited expanse of water. The experiments showed that the ordinary formula $R = K \omega V^2$ does not hold; that the various elements on which resistance to traction depends are not connected with one another by this or any other proportion of similar form. This is clearly seen from the following deductions, firstly for boats in rivers, and secondly for boats on canals.

Boats in Rivers.—1. *For a boat worked at a given speed the resistance to traction is* not *proportional to its immersed midship section* ω. This fact is shown by the following Table 1, taken from the results of M. de Mas' experiments upon a boat tried at successive draughts of 3·28 and 4·27 and 5·25 feet; the figures are embodied in M. Derôme's paper upon this subject, which was presented to the sixth International Congress on Inland Navigation in 1894, and to which the author is indebted for the following information. It will be seen that for one and the same speed the resistance to traction increases less quickly than the immersed section.

TABLE 1.—*Resistance of Boats to traction in Rivers.*

Speed per second.	Absolute Resistances at absolute draughts of			Relative Resistances at relative draughts of		
	3·28 ft.	4·27 ft.	5·25 ft.	1·00	1·30	1·60
Feet.	Lbs.	Lbs.	Lbs.			
1·64	85·98	97·0	119·05	1·00	1·13	1·38
3·28	284·4	315·3	357·1	1·00	1·11	1·26
4·92	617·3	694·4	782·6	1·00	1·13	1·27
6·56	1106·7	1276·4	1463·9	1·00	1·15	1·32
8·20	1774·6	2101·0	2466·9	1·00	1·18	1·39

2. *For a boat of given draught the resistance is* not *proportional to the square of the speed.* Although this fact is evident from Table 1, it is more clearly demonstrated by the results of a series of experiments on the different kinds of boats of which the resistances are given in Table 3. The results for the *Toue* have been worked out in Table 2 at a draught of 3·28 feet and at speeds of from 1·64 to 8·20 feet per second, or 1·12 to 5·60 miles per hour; and also at a draught of 5·25 feet for the same speeds. In Plate 28 this Table has been plotted as a diagram, giving the resistances actually observed, and as calculated from the formula $R = KV^2$, where the value of K is 31·97 for 3·28 feet draught, and 44·25

TABLE 2.—*Observed and Calculated Resistance of the "Toue" to traction in river. See Plate* 28.

Speed per second. V	Square of Speed. V^2	Resistance at draught of 3·28 ft.		Resistance at draught of 5·25 ft.	
		Observed.	Calculated. $K = 31\cdot97$	Observed.	Calculated. $K = 44\cdot25$
Feet.		Lbs.	Lbs.	Lbs.	Lbs.
1·64	2·6896	85·98	85·98	119·05	119·05
3·28	10·758	284·4	344	357·1	476
4·92	24·206	617·3	774	782·6	1071
6·56	43·034	1106·75	1376	1463·9	1904
8·20	67·24	1774·6	2150	2466·9	2975

for 5·25 feet draught. It would thus seem that, the greater the draught of the boat, the larger is the discrepancy between the observed and calculated resistances, especially at the higher speeds. The following Tables 3 and 4, which are also plotted in Plate 29, give the resistance to traction of the boats experimented upon at speeds between 1·64 and 8·20 feet per second, or 1·12 and 5·60 miles per hour; and also their submerged dimensions.

TABLE 3.—*Resistance of four Boats to traction in river. See Plate* 29.

Speed per second.	Péniche.	Flûte.	Toue.	Prussian.
Feet.	Lbs.	Lbs.	Lbs.	Lbs.
1·64	253·5	167·55	77·2	48·5
3·28	749·6	436·5	220·5	176·4
4·92	1701·9	793·7	518·1	407·8
6·56	3223·1	1686·6	1047·3	769·4
8·20	—	2447·0	1752·8	1283·1

TABLE 4.—*Dimensions of submerged part of four Boats in Table* 3. *See Plate* 29.

Kind of Boat.	Length.	Average midship Width.	Depth.	Total Displacement.	Immersed midship Section ω
	Feet.	Feet.	Feet.	Tons.	Sq. Ft.
Flemish Péniche .	125·30	16·40	5·94	337	97·38
Flûte of Upper Seine .	122·84	16·47	4·82	256	79·40
Toue of the Saône .	118·38	16·47	4·46	236	73·49
Prussian boat . .	111·90	16·11	4·27	200	68·65

If the resistance to traction corresponding with a speed of 3·28 feet per second, or 2·24 miles per hour, be taken as unity, Table 3 becomes transformed as in Table 5 and in the plotted diagram, Plate 30; from which it will be seen that, with the exception of the *Flûte*, the resistance increases more quickly than the square of the speed V.

TABLE 5.—*Relative Resistance of four Boats to traction at different Speeds in river. See Plate* 30.

Speed V	Square of Speed $= V^2$ Absolute.	Square of Speed $= V^2$ Relative.	Péniche.	Flûte.	Toue.	Prussian.
Ft. p. sec.						
1·64	2·6896	0·25	0·34	0·38	0·35	0·28
3·28	10·758	1·00	1·00	1·00	1·00	1·00
4·92	24·206	2·25	2·27	1·82	2·35	2·31
6·56	43·034	4·00	4·30	3·41	4·75	4·36
8·20	67·24	6·25	—	5·61	7·95	7·28

3. *For a given boat the coefficient of resistance to traction* $\frac{R}{\omega V^2}$ —being the ratio which the resistance R to traction bears to the immersed midship section ω and to the square of the speed V—*is* not *independent of the speed, as it is assumed to be in the ordinary formula* $R = K \omega V^2$. According to the figures given in Tables 3 and 4 this ratio varies as shown in Table 6 and in the plotted diagram, Plate 31:—

TABLE 6.—*Coefficient of Resistance to traction in rivers. See Plate* 31.

Speed V Ft. p. sec.	Square of Speed V^2	Values of Coefficient $R \div \omega V^2$. Péniche.	Flûte.	Toue.	Prussian.
1·64	2·6896	0·9678	0·7843	0·3907	0·2624
3·28	10·758	0·7153	0·5106	0·2788	0·2388
4·92	24·206	0·7219	0·4130	0·2912	0·2455
6·56	43·034	0·7690	0·4935	0·3311	0·2604
8·20	67·24	—	0·4583	0·3547	0·2780

4. *For a given speed and draught the resistance to traction varies considerably, according as the wetted surface of the boat is more or less smooth.*

5. *For boats of the same form, and under otherwise similar conditions, and within the limits of the experiments, the resistance to traction is entirely independent of the length of the boat.* On this

point M. de Mas experimented with three boats of the *Flûte* build, having the same breadth amidships, and fore and aft shapes as nearly identical as possible, and differing only in the length of hull below water, which with a draught of 5·25 feet was as follows:—*Alma* 124·64 feet; *René* 99·44 feet; *Adrien* 67·44 feet. As shown in Table 7 and plotted in Plate 32, the total resistances of these three boats at the same speed were almost identical. The *Alma* and *René* were subsequently tried again at the same speeds as in Table 7, but with 1 foot less draught, namely 4·25 feet, when they gave resistances absolutely identical with each other. From these results it also follows that the resistance due to the build of the boat does not vary in the ratio $\frac{b}{L}$ which the breadth b amidships bears to the length L.

TABLE 7.—*Resistance independent of Length of boat. See Plate* 32.

Boat.	Length.	Displacement.	Resistance at speed per second of				
			1·64 ft.	3·28 ft.	4·92 ft.	6·56 ft.	8·20 ft.
	Feet.	Tons.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Alma	124·64	286	119·0	357	783	1464	2467
René	99·44	—	112·4	353	783	1466	2469
Adrien	67·44	148	112·4	353	783	1466	2469

Boats on Canals.—The same boats that had been tried on the river Seine were subsequently tried on the Bourgogne Canal at speeds increasing from 0·56 mile per hour by increments of 0·56 up to 2·8 miles per hour; and it was again found that, other conditions remaining unchanged, and within the limits and under the conditions of the experiments, the resistance to traction is independent of the length of the boat. It was also found that there is a considerable increase in the resistance to traction on passing from the river into the canal. Table 8 is drawn up for different boats and different draughts, and for speeds of 1·64 and 3·28 feet per second, or 1·12 and 2·24 miles per hour, which appear to be the extreme limits of speed adopted and practicable on French

TABLE 8.—*Resistance to traction in Canal and in River. See Plate* 33.

Draught.	Boat.	Wetted Section of Canal. Ω	Immersed Section of Boat. ω	$n = \frac{\Omega}{\omega}$	Speed 1·64 feet per second.			Speed 3·28 feet per second.		
					Resistance			Resistance		
					in Canal. R	in River. r	$\frac{R}{r}$	in Canal. R	in River. r	$\frac{R}{r}$
Feet.		Sq. Feet.	Sq. Feet.	Ratio.	Lbs.	Lbs.	Ratio.	Lbs.	Lbs.	Ratio.
5·25	Péniche	317·91	86·66	3·67	379·2	224·9	1·69	1896·0	663·6	2·86
	Flûte	„	86·44	3·68	246·9	119·0	2·07	1060·4	357·1	2·97
	Toue	„	86·44	3·68	240·3	97·0	2·48	1020·7	277·8	3·67
4·27	Flûte	317·91	70·30	4·52	154·3	97·0	1·59	626·3	315·3	1·99
	Prussian	„	68·68	4·62	119·1	48·5	2·45	474·0	176·4	2·69
	Margotat	„	69·98	4·54	116·8	46·3	2·52	434·3	147·7	2·94
3·28	Flûte	317·91	54·04	5·88	105·8	86·0	1·23	421·1	284·4	1·48

canals; R represents the total resistance to traction in the canal, and r in the river; $\frac{R}{r}$ is the ratio of the two resistances.

One noticeable fact which appears from Table 8 and from the plotted diagram, Plate 33, is that, for the same value of the ratio $n = \frac{\Omega}{\omega}$, the less the resistance to traction of a boat in the river, the greater will be the relative increase in the resistance to traction when the boat is transferred from the river into a canal: or inversely, the larger the tractive force in the river, the smaller will be the relative increase on transference into a canal. Thus the *Toue*, requiring 97·0 lbs. tractive force in the river, requires when transferred to the canal 240·3 lbs., being an increase of 2·48 times; whereas the *Péniche*, requiring 224·9 lbs. tractive force in the river, requires in the canal only 379·2 lbs., that is, an increase of only 1·69 times against 2·48 times for the *Toue*. The build of the boat is less important in a canal than in a river; hence it will not exert so great an influence on the resistance to traction.

Another notable fact observed from Table 8 is the rapidity with which the ratio $\frac{R}{r}$ of the resistances decreases when the ratio $\frac{\Omega}{\omega}$ of the sections increases. Thus for the *Flûte*, the only boat which has been experimented upon both in the river and in the canal at draughts of 5·25 and 4·27 and 3·28 feet, the relative variations in the two ratios are as shown in Table 9 for speeds of 1·64 and 3·28 feet per second, or $1\frac{1}{8}$ and $2\frac{1}{4}$ miles per hour.

TABLE 9.—*Ratios of Sections and of Resistances for the "Flûte" class.*

Draught.	Ratio of Sections $n = \frac{\Omega}{\omega}$	Ratio of Resistances $\frac{R \text{ in canal}}{r \text{ in river}}$. 1·64 ft. per sec.	3·28 ft. per sec.
Feet.			
5·25	3·68	2·07	2·97
4·27	4·52	1·59	1·99
3·28	5·88	1·23	1·48

It is important to know how the resistance of the same boat, loaded to the same draught, alters in passing from a canal of one section to a canal of another. Some experiments upon this point were made in 1894, of which the following is a brief account. It may be premised that the ratio $n = \frac{\Omega}{\omega}$, which the wetted section Ω of the canal bears to the immersed midship section ω of the boat, obviously cannot sink below unity; and also that, the more nearly the ideal conditions of smooth water are approached, the more nearly does the ratio $n = \frac{\Omega}{\omega}$ approach infinity. As a limit therefore it may roughly be said in a general way that, when $n = \frac{\Omega}{\omega} = 1$, $\frac{R}{r} = \infty$; and when $n = \frac{\Omega}{\omega} = \infty$, $\frac{R}{r} = 1$. In Table 10 and in the three plotted diagrams, Plates 34, 35, and 36, are given the values of the ratio of sections $n = \frac{\Omega}{\omega}$ and of the ratio of resistances $\frac{R}{r}$, obtained from experiments made with the *Jeanne*, a boat of the *Flûte* class, 99 feet long and 16·44 feet wide, towed in the river Seine and in four different canals, with draughts of 3·28 and 4·27 and 5·25 feet, and at speeds of 0·82 to 4·10 feet per second or 0·56 to 2·80 miles per hour. In the river Seine, where the minimum value of the ratio $n = \frac{\Omega}{\omega}$ was not less than 72·5, the ratio $\frac{R}{r}$ which the resistance R in a canal bears to the resistance r in a river, can without appreciable error be taken as 1·00. From Table 10 it will be seen that, with a draught of 4·27 feet and at a speed of 2·46 feet per second or 1·68 mile per hour, the ratio $\frac{R}{r}$ of the resistances of the *Jeanne* is only 1·38 in the Dérivation de Joigny, where the ratio n of sections attains a value of 6·39; while in the Canal du Nivernais, where the ratio n of sections falls to 2·94, the ratio $\frac{R}{r}$ of resistances rises to 3·82: that is, for a reduction to a little less than half in the ratio of the sections, the ratio of the resistances is nearly tripled. This example shows how great an influence the ratio of the sections has upon the resistance. The figures given in Table 10 are purely experimental, and not arrived at by any mathematical calculation. At the speed of 0·82 feet per second it will be noticed that the resistances in the river Seine are the same at draughts of 3·28 and 4·27 feet; this is probably due to the fact that the resistances were measured to the nearest kilogramme, and therefore a difference of less than 2 lbs. would not be noticed in converting the readings from French into English measure.

TABLE 10.—*Ratios of Sections* $\frac{\Omega}{\omega}$ *and of Resistances* $\frac{R}{r}$ *of boat "Jeanne" in different Waterways. See Plates* 34–5–6.

R = resistance to traction in Canal; r = resistance to traction in River.

Draught.	Waterway.	$\frac{\Omega}{\omega}$	0·82 ft. per sec.			1·64 ft. per sec.			2·46 ft. per sec.			3·28 ft. per sec.			4·10 ft. per sec.		
			R	r	$\frac{R}{r}$	R	r	$\frac{R}{r}$	R	r	$\frac{R}{r}$	R	r	$\frac{R}{r}$	R	r	$\frac{R}{r}$
			Lbs.	Lbs.		Lbs.	Lbs.		Lbs.	Lbs.		Lbs.	Lbs.		Lbs.	Lbs.	
3·28 feet.	River Seine . . .	116·04	26·5	26·5	1·00	28·7	28·7	1·00	145·5	145·5	1·00	244·7	244·7	1·00	383·6	383·6	1·00
	Dérivation de Joigny	8·31	26·5	,,	1·00	28·7	,,	1·00	149·9	,,	1·03	271·2	,,	1·11	458·6	,,	1·20
	Canal de Bourgogne	5·89	35·3	,,	1·33	103·6	,,	1·42	227·1	,,	1·56	407·8	,,	1·67	692·2	,,	1·83
	Canal de la Cure .	4·64	37·5	,,	1·41	108·2	,,	1·48	238·1	,,	1·63	452·0	,,	1·85	795·9	,,	2·07
	Canal du Nivernais .	3·82	39·7	,,	1·50	123·5	,,	1·70	284·4	,,	1·95	557·8	,,	2·28	1018·6	,,	2·66
4·27 feet.	River Seine . . .	89·30	26·5	26·5	1·00	83·8	83·8	1·00	172·0	172·0	1·00	295·4	295·4	1·00	474·0	474·0	1·00
	Dérivation de Joigny	6·39	30·9	,,	1·17	105·8	,,	1·26	238·1	,,	1·38	440·9	,,	1·49	756·2	,,	1·60
	Canal de Bourgogne	4·54	48·5	,,	1·74	154·3	,,	1·84	341·7	,,	1·98	621·7	,,	2·10	1073·7	,,	2·26
	Canal de la Cure .	3·57	50·7	,,	1·92	178·6	,,	2·13	410·0	,,	2·38	813·5	,,	2·75	1501·4	,,	3·17
	Canal du Nivernais .	2·94	70·5	,,	2·67	255·7	,,	3·05	657·0	,,	3·82	1389·0	,,	4·70	2645·6	,,	5·58
5·25 feet.	River Seine . . .	72·49	28·7	28·7	1·00	90·4	90·4	1·00	187·4	187·4	1·00	319·7	319·7	1·00	511·4	511·4	1·00
	Dérivation de Joigny	5·19	39·7	,,	1·42	141·1	,,	1·56	326·3	,,	1·74	619·5	,,	1·94	1124·4	,,	2·20
	Canal de Bourgogne	3·68	70·5	,,	2·46	241·7	,,	2·71	562·2	,,	3·00	1047·0	,,	3·28	1838·8	,,	3·59
	Canal de la Cure .	2·90	72·8	,,	2·56	264·6	,,	2·93	687·9	,,	3·67	1532·0	,,	4·79	2965·2	,,	5·80

Deepening of Canal.—The normal dimensions of French canals, as defined by the law of 5th August 1879, and shown in Plate 37, are 32·8 feet width at bottom, 52·5 feet at top, and 6·56 feet depth, giving a wetted section Ω of 279·7 square feet. These canals are intended to carry boats 16·4 feet wide at midship section with 5·91 feet draught. The immersed midship section ω is then 96·9 square feet, and the ratio of the sections $\frac{\Omega}{\omega} = 2{\cdot}89$. This is to a hundredth the ratio which in Table 10 the section of the Canal de la Cure bears to that of the *Jeanne* at a draught of 5·25 feet; and in this instance the ratio of resistances $\frac{R}{r}$ at a speed of 2·46 feet per second or 1·68 mile per hour is seen to be 3·67. Supposing the canal be deepened by 3·28 feet, as shown dotted, the width at top and the slope of the sides remaining unaltered, and the dimensions and draught of the boats remaining the same, the wetted section of the channel becomes 371·3 square feet, instead of 279·7; and the ratio of the sections rises to 3·83, instead of 2·89. This is to a hundredth the ratio which in Table 10 the section of the Canal du Nivernais bears to that of the *Jeanne* at a draught of 3·28 feet; and in this instance the ratio of resistances $\frac{R}{r}$ at the same speed of 1·68 mile per hour is seen to be 1·95. It may therefore be pointed out that, if the standard canal in France were deepened by 3·28 feet, the resistance to traction of the boats at their maximum draught would be reduced nearly one half for a speed of 2·46 feet per second or 1·68 mile per hour.

Formulæ.—The foregoing results obtained by M. de Mas afford a means of checking the formulæ usually adopted for the resistance of boats to traction upon canals. The two following are believed by the author to be the formulæ most generally employed, in which $n = \frac{\Omega}{\omega}$:—

$$R = K \omega V^2 \frac{1}{n+2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$R = K \omega V^2 \left(\frac{n}{n-1}\right)^2 . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The first formula was propounded by Du Buat in the last century, and has been applied by D'Aubuisson to the resistance of boats upon the Midi Canal. The second is deduced from the formula used for an open expanse of water —namely $R = K \omega V^2$ — by substituting for the absolute speed of the boat in open water its relative speed in relation to the water flowing backwards past it, on the assumption that the water would pass back from bow to stern at a uniform speed through the narrowed section $\Omega - \omega$. From the results now obtained by M. de Mas are deduced the three following conclusions:—first, for a boat hauled at a given speed V the resistance to traction is not proportional either to $\frac{\omega}{n + 2}$ or to $\frac{\omega \, n^2}{(n - 1)^2}$; second, for a boat kept at a constant draught the resistance to traction is not proportional to V^2; and third, for a given boat the proportions $\frac{R \, (n + 2)}{\omega \, V^2}$ and $\frac{R \, (n-1)^2}{\omega \, V^2 \, n^2}$ are neither of them independent of the speed. Hence it will be seen that the two above formulæ can give only wrong results. Recently M. de Mas has been engaged on experiments with a view to determine the variation of resistance offered to a boat, when the area of cross section of a canal is kept the same while its width and depth are altered; his results however have not yet appeared.

Depth of Canal.—With regard to the influence of depth upon resistance to traction, a French engineer M. Barbet made some experiments on the River Scarpe and on the Sensée Canal, by observing the time taken by boats of 16·4 feet width and 5·91 feet draught in entering from down stream into the locks, when hauled by a constant force; and it was found that the time varied inversely with the depth of water on the lower mitre sill, as shown in Table 11 and plotted in the diagram, Plate 38, in which the figures are the averages of many experiments. Hence he concludes that by increasing the depth of water on the sill to 7·38 feet or 8·54 feet

TABLE 11.—*Time taken by Boats to enter Locks. See Plate* 38.

Name of Lock.	Depth of Water on mitre sill.	Time taken by boat in entering lock.
	Feet.	Seconds.
Augustin	6·67	576
Gœulzin	6·90	355
Estrées	7·38	260
Fressies	8·54	216

the resistance to traction would be materially reduced; but he thinks that a further increase of depth would scarcely be justified by any sufficient gain. These results confirm the experiments made by Bossut in the last century with a balk of wood 2·13 feet square and 6·46 feet long, immersed to half its depth in water. Those old experiments apparently prove that beyond a certain limit the depth of water below a floating body has but little effect on the resistance to traction; and the above experiments by M. Barbet confirm this conclusion. It will be interesting to see whether those of M. de Mas, which are now being carried out with much greater accuracy than was possible on the Canal de Sensée, agree with the foregoing. Although Bossut's experiments may seem antiquated, yet their practical bearing on the size and form of boats to be used on canals of given section is so obvious as to render them worthy of attention.

It has been found over and over again that, as the depth of a canal is augmented, the ease with which a boat can be towed is increased. In the discussion upon the late Mr. F. R. Conder's paper upon "Speed on Canals" (Proceedings Inst. C.E., 1884, vol. lxxvi, page 160), it was stated by Mr. Robert Gordon (page 198) that within the limits of his experience retardation of speed and deficient steering power "were much more strikingly developed in shoal water, with only a few feet between the bottom of the vessel and the bed of the canal, whatever the breadth of the stream might be, than in a restricted narrower section of greater depth." On the Forth and Clyde Canal, on which there is steam navigation, and where, according to Sir Arthur Cotton, the ratio of wetted section Ω of canal to immersed cross section ω of boat amounts to 3 : 1, it is found that a higher speed than five miles per hour cannot be adopted, because above this speed the water is not delivered quickly enough at the stern to admit of effective steering. In the discussion upon Messrs. Clegram and Healy's papers in 1866 (Proceedings Inst. C.E., 1866, vol. xxvi, page 1) the two following conclusions were drawn by Mr. William Beardmore (page 43):—"First, that with any flat-bottomed vessel propelled by a screw, immersed to its full diameter in a canal where the sectional area of the vessel was less than one-seventh part of that of the whole waterway, the speed was sensibly affected (independently of the laws of motion of bodies through narrow canals) wherever the depth below the vessel's bottom did not exceed two-thirds of the diameter of the screw. Secondly, that when the sectional area and depth of the canal were less than the above proportions, the velocity at which the screw could be worked with advantage was limited by the speed with which the water could pass beneath the boat so as to feed the screw. In other words, if a speed were obtained beyond that at which the water would pass to the screw, the engine power was wasted in churning the bottom water."

M. Fleury, a French engineer, observes that it has been experimentally proved that, for the same draught and velocity, the traction of boats, which upon the canal from the Marne to the Rhine is very fatiguing for horses, is less so upon the canals of the Oise and Escaut, and is comparatively easy upon the Canal de Saint-Quentin. Although the variation in the ratio $\frac{\Omega}{\omega}$ of the sections, as shown in Table 12, is not great, yet the small increase of depth below the bottom of the boat has a marked effect on the resistance to traction. Until M. de Mas' latest experiments are published, which the author believes will constitute the only complete series of experiments hitherto made upon this subject, the influence of depth and width of water upon the resistance to traction of a boat in a narrow channel must remain undetermined. Meanwhile one thing known at the

TABLE 12.—*Depth of Canals.*

Name of Canal.	Width at bottom. Feet.	Depth of Water. Feet.	Ratio of Sections $\frac{\Omega \text{ of canal}}{\omega \text{ of boat}}$
Canal from Marne to Rhine .	32·81	6·56	2·89
Canal from Oise to Aisne .	32·81	7·22	3·25
Canal de l'Escaut . . .	36·09	7·22	3·50
Canal de St. Quentin . .	39·37	7·55	3·74

present time is that the ordinary formula $R = K \omega V^2$ is inaccurate, or at least incomplete.

Speed.—The speed attainable upon a canal must necessarily be limited by the consideration of the preservation of the banks. Up to a speed of three miles per hour it was found by Dr. Pole that no waves were formed which had an injurious effect on the sides of the canal; but above that speed breaking waves became developed, and had a most destructive effect upon the banks. At moderate speeds it has been found that the wasting of the banks extends only about one foot above and one foot below the water level. The difficulty of preserving the banks was one of the great hindrances to the use of steam power upon canals. When it was first determined about 1860 to try towing by steam upon the Ashby-de-la-Zouch Canal, the railway owning the canal objected; and the matter was referred to Dr. Pole, who tried a boat propelled by a screw at different speeds, with the result already mentioned, namely that no damage was done up to three miles per hour, but that above this speed breaking waves were formed. The highest speed allowed in France is from 6 to 8 kilomètres or about 3¾ to 5 miles per hour, while in England three miles per hour is the usual speed. In narrow canals, and in tunnels such as that on the Canal de Saint-Quentin, the speed has to be further reduced, owing to the heaping up of the water in front of the boat. An instance is cited by Lermoyez in 1863, in which the last of a train of barges was left on a dry keel, owing to the water not being able to flow backwards past the boats quickly enough to supply the void caused by their passage. They acted indeed like the plunger of a pump, forcing the water before them; and the only way in which they could be moved along was by waiting for intervals of twenty minutes until the water had returned to its normal level in the canal. Even in a moderately wide canal, by keeping the traffic moving continuously in the same direction over a distance of thirty miles for a whole day, Scott Russell found the water raised eighteen inches higher at one end of the canal and lowered eighteen inches at the other, making a total difference of level of three feet (Proceedings Inst. C.E., 1884, vol. lxxvi, page 200).

On the canal from the port of Edam on the Zuyderzee to the great North Holland Canal at Schouw (viâ Monnikendam) the maximum speed of steamboats is regulated in a special way. The canal is of small section, and when steamboats travelled at an unlimited speed the damage suffered by the banks and slopes was alarming. It was decided to fix maximum speeds to be allowed; and experiments showed that the rate of progress of the boat no longer increased beyond a certain speed of revolution of the screw, and that at quicker driving the extra work of the engine served only to increase the wash of the water and the destruction of the banks. With a limited speed of revolution of the screw, nearly the same rate of progress could be obtained without damaging the banks. Since then the maximum speed of screw has been fixed at 120 to 140 revolutions per minute, according to the size of the canal. This would seem to favour the use of large propellers running at a low speed of revolution, in preference to small propellers revolving at a high speed. The same experiments prove that on any navigable waterway there is a speed of boat corresponding with a maximum efficiency, which depends upon the proportion between the dimensions of the canal and those of the boat. In order to increase the speed of boat, the first step must be to diminish the resistance encountered by the water in flowing backwards past the boat: that is to say, the form of the boat must be changed and its cross section diminished, or else the canal must be enlarged.

With regard to altering the shape of the boat in order to gain increased ease of traction, the experiments of M. de Mas may be again referred to. He has experimented with two builds of boat already mentioned, which are known locally as a *Péniche* and a *Toue* (ferry-boat), having the same length of water line and the same width amidships. The *Péniche* is but slightly rounded at each end, and the bottom is only slightly cut away at the stem and the stern; the boat is therefore full bodied, the coefficient of fineness being 99 per cent., that is, the ratio which the volume of the displacement bears to the parallelopiped circumscribing the immersed hull is 99 per cent. The *Toue* is square at the stern, but rather more cut away at the bow than the *Péniche*; and its coefficient of fineness is consequently reduced to 97 per cent. Both these builds of boat have flat bottom and parallel sides. With a draught of 4·27 feet and at a speed of 1·68 miles per hour the resistance of the *Toue* is 232 lbs. less than of the *Péniche*; while with a draught of 5·25 feet and at the same speed the decrease is 366 lbs. The loss of carrying capacity in the *Toue*, consequent on the difference in shape, is 5·9 tons: so that for this small loss, reducing her carrying capacity to 236 tons (Table 4), there is a considerable diminution of resistance to traction, and a consequent increase in speed might be obtained. The resistance of boats to traction is also increased in going round curves; and M. Flamant (Annales des Ponts et Chaussées, 1881, vol. i, page 214) has shown that the power required to tow a boat round a curve of 328 feet radius is just double that required on a straight stretch of canal having the same cross section as the curve. French canals however are usually made of extra width in curves; and it is then found that a curve of 328 feet radius does not materially increase the resistance to traction on a canal intended to carry boats of 125 to 128 feet length and 16½ feet width.

Mechanical Propulsion.—There are four different methods in use for the mechanical traction or propulsion of boats upon canals, which will be taken in the following order:—(1) propulsion by screws worked either by steam, by petroleum motors, or by electricity; (2) hauling upon a submerged chain or wire rope lying along the bed of the canal; (3) attachment to an endless running rope working along the canal bank; (4) towing by a locomotive running along the canal path. These the author believes are the only plans at present in use on canals, or passing through the experimental stage. Upon the Continent a few stern-wheel steamers are in existence on rivers; but they are seldom used on canals, because they occupy so much room in the locks, and the stern wheel takes up a good deal of valuable space that might be occupied by cargo.

Propulsion by Screws.—In America in 1871 competition was invited for introducing upon the canals in the State of New York some other method of haulage than by animal power. From the magnitude of the premiums offered, amounting to £20,000, it is evident that mechanical propulsion was thought highly important; it was expected that its introduction would materially lessen the cost of traction and increase the traffic, and these expectations have been justified by the results obtained. The requirements were: that the inventions should be tried at the expense of the owners; that the boats should carry at least 200 tons of cargo, as well as machinery and fuel; that the average speed should be not less than three miles an hour without injury to the banks; that the boats should be readily stopped and backed by their machinery; that simplicity and economy should be elements of consideration; that the devices should be readily adaptable to existing canal boats; and that they should lessen the cost and increase the facility of transport on canals.

The first designs presented were intended to overcome the wave, which it was thought a speed of three miles an hour would cause; but this difficulty, as had already been shown some years before by Dr. Pole's experiments, was more apparent than real at that speed, because a wave of sufficient height to be detrimental is caused rather by the speed exceeding three miles an hour than by the actual nature of the machinery used for propulsion. Boats carrying light freight and passengers, and running at six miles an hour, do cause injury to the banks. During the first season of the competition only one steamer was offered, namely the *Dawson*, which had a screw in the bow forcing the water backwards through a passage under the boat; but she did not come up to the requirements. The next season saw twelve steamers offered, of which only three made the three trips required from Buffalo to New York and back; none of the trials were entirely satisfactory. In 1873 five new boats were offered, four of which presented no special peculiarities, while the fifth was propelled by a compound rotary engine and had the screw placed in the bow at the orifice of a passage way running along under the boat to the stern; it was found however that this boat went much better backwards than forwards, and she was accordingly run backwards during the season. Another boat, the *State of*

New York, had a compound condensing engine with two high-pressure cylinders and one low-pressure, driving a single four-bladed screw; her build was the same as that of the "Baxter" steamers now extensively used upon the Erie Canal. Her owner received the sum of £7,000 on condition that he placed upon the canals of the State during the next season seven steamers fully equipped and equal to the *State of New York*. The owner of the *William Newman* received £3,000 on condition that he placed three similar steamboats on the canals next season; and the owner of the *Central City* received £1,000 on condition that he put this boat in service next season. These conditions were all complied with, and the amounts paid.

The principal changes made since that time have been connected with the improvement of some of the details of the boats, which have resulted in the present canal steamers, and also in the use of these steamers for conveying through the canal one, three, or five ordinary canal-boats fully laden. The steamer usually pushes one boat in front of it, and tows two other boats behind it, which are kept together in the same way as the coupled horse-boats at present in use. In addition to its fuel the steamer carries 180 tons of cargo; the canal boats carry 250 tons each. In the coupled horse-boats, one boat is directly behind the other, their bow and stern being in actual contact. They are coupled by ropes running from the stern of the forward boat, through blocks on each side of the rear boat, and returning to a steering wheel on the forward boat. The ropes are not connected with the rudder of the rear boat, which is left to swing freely; and the boats are steered by using the whole rear boat as a rudder. The standard steam canal-boats are 18 feet wide and 90 feet long. The engine commonly in use was designed by Gordon W. Hall, and is generally known as the Hall engine; another engine designed by the Pound Manufacturing Co. has been placed upon a number of boats. Both these engines are simple condensing engines, with cylinders of 12 to 14 inches diameter, and 16 inches stroke. They have adjustable cut-off gear, feed-water heaters, and surface condensers. The feed and air pumps are worked by a single beam, which is usually actuated by an eccentric on the crank shaft, but sometimes by the cross-head. The arrangement for securing circulation of the water for the surface condenser is peculiar; by the motion of the boat and of the screw, the circulating water is forced up, without pumping, through the opening in the bottom of the condenser, and out at the stern. In a modified form this plan is adopted in some of the torpedo boats and destroyers in the navies of this and other countries.

Aire and Calder Navigation.—The method of propulsion in use on the Erie Canal is not unlike that which up till lately was in vogue on the Aire and Calder Navigation, and has proved so successful. Here a steam-tug in the rear propelled in front of it a train of eleven boats, each carrying about 40 tons. The boats are 20 feet long, 16 feet wide, and 7½ feet deep. A tender or dummy boat was attached to the front of the train, in order to make a stem, because the vessels of the train themselves are not strictly boats, but merely iron boxes for stowing cargo in. It was supposed that by having the tug behind the train, instead of in front, greater control could be exercised over the boats in steering them. The author has been informed however that this plan has been discontinued, and that at the present time the tug is placed in front of the train. The boats are threaded together by means of wire rope controlled by two cylinders, which are self-acting and are under the charge of the steersman. By lengthening or shortening the ropes on each side of the train, it can be guided in any curve, while the several vessels composing it are left to rise and fall separately according to any little variation of head line; the train is not bound rigidly in any way. Side buffers are attached to the ends of each boat, which have a tendency to bring them back again into a straight line in the event of any slight disorganization caused by wind and water; the train and its direction are under the full control of the steersman. This plan Mr. Bartholomew considers could not be introduced on many of the canals in England, unless the locks were made longer; but he would prefer inclined planes for getting from one level to another. The locks on the Aire and Calder Navigation are long enough to admit one of these trains at a time; so that after having been made up they do not need to be uncoupled until they arrive at their destination. The cost of conveying mineral traffic by these boat trains is low; it will be dealt with subsequently.

Leeds and Liverpool Canal.—Tugs propelled by screws are in use also upon the Leeds and Liverpool Canal, of which the cross section is at present small, and is now being enlarged at considerable expense. Some years ago Mr. William Wilkinson of Wigan suggested utilizing ordinary barges as tugs, by putting in small engines to drive a screw propeller as large as could be made available without too high a percentage of positive slip; and he proposed further to make each tug carry a paying cargo. In conjunction with Mr. Charles White, the engineer of the canal, he fitted up one of the barges with engines. When tried it was found that it was able to tow two others at a speed of 2 miles an hour; in parts of the canal where the depth is greater the speed rose to 2¾ miles an hour; and under similar conditions with only one barge in tow as high a speed as 3½ miles an hour has been attained, but then a rolling wave was set up which caused injury to the banks, thereby confirming Dr. Pole's observations upon the Ashby-de-la-Zouch Canal. The results proved so satisfactory that some forty more barges have since been fitted up for the same canal by Mr. Wilkinson's firm. The form of propeller adopted was arrived at by an exhaustive series of experiments, and its best results are obtained in shallow water.

Engines.—In conjunction with the Leeds and Liverpool Canal Co. experiments have also been made by Mr. Wilkinson with the object of finding out the best form of engines to use in the barges. The following eight kinds have been tried:—(1) simple diagonal with two cylinders, and (2) compound ditto jet-condensing, and (3) compound ditto surface-condensing; (4) compound with four cylinders, two high-pressure and two low, surface-condensing, and (5) ditto jet-condensing; (6) compound inverted vertical two-cylinder tandem, high-pressure over low, surface-condensing; (7) compound with two cylinders side by side, non-condensing; and (8) compound diagonal with four cylinders, two high-pressure and two low, non-condensing, with 140 lbs. steam, and cranks at right angles. The two last, Nos. 7 and 8, give the best results. With No. 8, which is now the standard engine on the canal, the author is informed that the following performance is obtained. The tug, 62 feet long by 13 feet wide and with 3½ feet draught, carries 28 to 30 tons of cargo besides her machinery and fuel, and tows two barges 62 feet long by 14 feet wide, each carrying 36 to 40 tons, from Liverpool to Leeds, a distance of 128 miles with ninety-seven locks, on a consumption of 43 lbs. of good gas coke per mile, locks included: which is equal to 0·39 lb. of coke per ton-mile, assuming the boats to be fully loaded. Including loading and discharging, the double trip of 256 miles total is made in six days. It is stated by Sir William Bailey that these steamers have conduced much to the punctuality and regularity of working on the canal, and that in comparison with horse towage they have accelerated the speed some 40 per cent.

Upon some of the canals in the Netherlands small screw-boats are fitted with petroleum motors, constructed by Van Rennes of Utrecht, which drive the screws through belting; but the author has not been able to obtain any particulars of their actual working. A number of projects have been brought forward for the conversion of existing boats into tugs carrying their own cargo, with the least possible structural alteration. In France it has been proposed to use small motors, which can be put on board at the outset of a trip, and removed when the journey is ended. This plan is proposed by Messrs. Molinos and De Bovet to be used on canals where tunnels occur, in conjunction with electric towage by means of De Bovet's method of magnetic adhesion. The electric wires would be carried along the canal, and current supplied to the motors through a trolly, as on the American tramways; the motors would be capable of giving out 3 horse-power, and of being easily removed when the need for towage ceased. This idea the author believes has not been carried out at present.

In Ireland Mr. Henry Barcroft of Newry has worked out a method of propulsion with large-bladed propellers partially immersed, which is applicable to nearly all existing canal boats without any important structural alteration. As his plan has already been brought before the Institution at Manchester in 1894, and again at the last Meeting, and the members have also had an opportunity of seeing it at work on Carlingford Lough at the Belfast Meeting last summer, it is unnecessary for the author to do more than to call attention to it in the present paper.

Another proposal is to employ a totally submerged propeller, which can be raised and lowered to suit the varying draught of the boat, and can be turned in any direction for steering, thereby dispensing with a rudder. On the Bourgogne Canal a trial is being made of a small screw driven electrically, and fixed in the rudder of the boat. A large steel box carrying the motor and screw is attached to the stock of the rudder; the box displaces a volume of water more than equal to its own weight, and is thus capable of floating alone upon the canal. It has a total length from front to back of 8 feet 2 inches, a height of about 5 feet 10 inches, and a width of about 1 foot 5 inches. This width is continued only for a distance of about 5 feet 10 inches backwards from the front end; after that it is cut away to allow of a freer run aft. The motor is fixed in the box upon a foundation plate secured to the bottom, and its shaft is connected direct to the screw. The entire box, containing motor and screw, weighs about 15¾ cwts., and floats with a draught of from 4 feet 1¼ inches to 4 feet 3¾ inches.

Some comparative experiments on screw and hydraulic propulsion have been made by Mr. Arthur D. Ellis and Mr. W. B. Crichton, of Messrs. Thwaites Brothers, Bradford, on the Leeds and Liverpool Canal above Skipton, where the canal is 4 ft. 5 ins. deep and there is practically no current. The results are plotted in the accompanying diagram, Plate 44, in which each of the curves has been drawn through twelve to fourteen points, so that there can be no doubt as to their accuracy. The same engine was used throughout, first for driving the screw, and then for driving the Capell centrifugal pump when the boat had been altered for hydraulic propulsion according to the arrangement shown in Plates 40 and 41. Owing to the construction of the boat, the discharge of water had to be made on each side of the stern post by means of a breeches pipe. This may perhaps have somewhat reduced the efficiency of the hydraulic arrangement. One of the most noticeable features of these experiments is that, with the Capell turbine having a disc of 16 inches diameter and 3¼ inches width and making about 150 revolutions per minute, and with nozzles on the discharge orifices, a speed of 2¾ miles per hour was obtained for the same horse-power with hydraulic propulsion as with the screw, Fig. 13, Plate 44; but above this speed the power required for the hydraulic propulsion increased at a more rapid rate than for the screw. Without the nozzles the boat could hardly be moved along; but with them the results shown in Plate 44 were obtained.

Hauling upon a Submerged Chain or Wire Rope.—A favourite means of traction, especially in France and Belgium, consists in hauling upon a chain or wire-rope, fixed at each end, and laid along the bed of a canal or canalized river; but it is only on the most frequented canals that it can be advantageously applied, and only in a certain number of reaches of great length. It is extensively used in the tunnels upon the canals in the North of France. To render it remunerative, there must be a considerable amount of traffic, and the tolls should be somewhat lower than those for towing by horses; also the reaches should be long enough for the trains of boats to regain the time lost in locks. According to M. Derôme, with chain haulage on a much frequented canal the average speed of a train of four boats cannot practically exceed 2¼ miles per hour. That of a boat drawn by horses is usually 1¼ mile per hour. Haulage is superior to tugs only when there is any current to contend against; its advantage diminishes as the velocity of the opposing current decreases.

Hauling on a submerged chain is done by means of two grooved drums, one behind the other in the line of the chain with their axes parallel to each other and about 10 feet apart, round each of which the chain is generally wound about four half turns, making four turns round the pair. As far as the preservation of the chain is concerned, the plan is defective. If the grooves in the drums are not absolutely equal in diameter, the chain cannot help slipping, and abnormal strains then arise in the intermediate lengths, often exceeding the tractive force on the stretch ahead upon which the boat is hauling itself. The chain moreover is bent as many as eight times during its four half turns round the drums; when working in sandy or muddy water the alternate bending and straightening is highly detrimental to its durability. The necessity for one boat throwing the chain off when meeting another is also a great objection, as this is not easy to do, and causes a considerable loss of time. It has however been got over to a certain extent in M. De Bovet's magnetic tow boat *Ampère*, now in use on the lower Seine, where the chain passes over only one pulley, which is magnetized and thus causes it to adhere. The wetting of the chain even by soapy water does not cause a loss of more than 10 per cent. of the tractive power. Up to the present this boat has been successful; the chain is used only for going up the river; on the downward journey the boat is propelled by an ordinary screw. In order to avoid having to throw the chain off when meeting another boat, it has been proposed to use two chains, which however would necessitate widening the bottom of the canal in order to prevent them from getting entangled, and even then the danger would still exist in curves. In 1860 some experiments were made on the Grand Canal in Ireland with chain haulage, but it was found impracticable. Although it has been so successful on the Continent, its advantages have not been sufficiently great to lead to its adoption in this country.

Upon the Rhine a wire rope is used instead of a chain (Proceedings 1869, page 240). The rope is laid in the bed of the channel, and is taken up over a wheel at the bows, passed round a clip drum, and then dropped astern. Some experiments with a wire rope were made by Sir Leader Williams on the Bridgewater Canal; but where there is much traffic in the opposite direction, and many bends in the canal, the wire-rope plan is found to be practically unworkable. Cable towing was also tried upon the Erie Canal in the United States. The first cable of 34 miles length was laid down in 1872, and in 1879 there were over 80 miles of it; but it was abandoned after ten years' trial.

Electric Haulage.—Electric haulage on a chain has lately been started upon the Bourgogne Canal, and has given complete satisfaction up to the present time. It was designed by M. Galliot, Ingénieur des Ponts et Chaussées, under the direction of M. Fontaine, chief engineer of the Bourgogne Canal, and was approved by the Minister of Public Works on 8th February 1893; the work was immediately begun, and was finished on 15th July following. The reach of canal upon which the system has been applied is 3¾ miles long, and includes a little over 2 miles through a tunnel; the width of waterway is about 23 feet in the open and about 20 feet in the tunnel, while the depth varies from 7 feet 4½ inches to 7 feet 10½ inches. From 1867 to 1883 barges were towed by a steam tug hauling on a submerged chain; the plan worked well, but was dear, the cost of maintenance being high. In 1888, the old tug boats being no longer serviceable, it was decided to utilize the waterfall at the canal locks for driving turbines to generate electricity, and to work this reach electrically. The ground having been surveyed, it was decided to make a fall of 23 feet at Pouilly at the Seine end, and another of 26¼ feet at Escommes at the Saône end. The available water power at Pouilly is 20·7 horse-power and at Escommes 11·8 horse-power, making a total of 32½ horse-power. Two dynamos are used, which are shunt-wound Gramme machines, connected in series: that at Pouilly is constructed to supply a normal current of 30 ampères at 370 volts, and the other at Escommes furnishes 30 ampères at 280 volts. A conducting wire running along the canal bank joins two opposite poles of the machines; and from each of the two remaining poles a separate wire runs along the same bank parallel to the first wire and below it; by means of the two lower wires the current is conveyed to the motor. When the turbines are running at their normal speed, the total electromotive force is 370 + 280 = 650 volts; the resulting current does not generally reach 30 ampères, but varies between 12 and 25 ampères according to the cargo towed; for a current of 25 ampères the loss of power is 180 volts. The motor is capable of absorbing a maximum of 18½ horse-power; it is rarely however that such a high power is required. The mode of connection by the wires presents the advantage that the length of conductor traversed by the current remains always the same, on whatever part of its journey the tug boat may be. The switchboard on the tug has a rheostat of 180 ohms for admitting the current gradually to the motor. The governor regulating the admission of water to the turbines is worked electrically; it allows a variation in voltage of only 10 per cent. when a tug is starting, and normally a variation of only $2\frac{1}{2}$ per cent. A battery of accumulators is connected in parallel with the conducting wire, and works simultaneously with the dynamos; the connection is continuous, so that the accumulators act as equalisers. The battery working alone is sufficient for two journeys in each direction; it is placed in the cellar of the resident engineer's house. The accumulators have been found however to be of but little use; and M. Galliot states that, if the work were to be done over again, he should dispense with them, and should also use series-wound dynamos, instead of shunt-wound as at present. The total length of circuit traversed by the current being about $7\frac{1}{2}$ miles, the resistance is 3·9 ohms. In ordinary working at 600 volts with a current of 20 ampères the efficiency is 87 per cent. The three wires of the line are so arranged as to occupy in section the corners of an isosceles triangle 3·9 inches high, the two lower wires being those along which the current travels to and from the motor. For keeping the wires in their required position, insulators of a special form are used. The line so constituted forms an open circuit; to close the circuit, it is only necessary to place the two lower wires in contact with the poles of the motor, which is done by means of two trolleys carried by the boat. As on American tramways, the trolleys are composed of two long jointed arms, each terminating in a small roller, which travels along the conductor on the bank of the canal, and conveys the current to the motor leads that run through the arms. At the end of the arms of the trolleys the conductors are connected to the switchboard, and thence to the poles of the motor. The latter is a series-wound Gramme machine, which on a brake trial at 900 revolutions per minute, with 30 ampères and 550 volts, gave 19 brake horse-power; the mechanical efficiency was 85 per cent. The motor receives a greater or less supply of power in proportion to the trains it has to tow; it works well with different cargoes in tow, and is remarkably free from sparking. It is connected to the chain drum by means of belting; the pulley of the motor is 11·8 inches diameter, and the fly-wheel on the chain drum 5 feet 10½ inches, or six times the pulley. The boat is geared for two nominal speeds of 1·79 and 3·13 miles per hour; the actual speed of course varies largely with the weight of cargo towed. The tug is 49 feet 2½ inches long, 10 feet 6 inches wide, and 3 feet 11¼ inches deep, with a draught of 1 foot 5¾ inches. Fore and aft she is covered with fluted sheet-iron; and a length of 26 feet 3 inches amidships carries a cabin of thin sheet-iron to protect the machinery from the weather. In order to prevent the chain from bespattering the boat, it is entirely enclosed in a U-shaped trough, which is covered by a half round lid of thin sheet-iron. The chain enters and leaves the boat through two holes similar to those on river steam-tugs. There are two rudders, one at each end, and each connected to a wheel placed at the opposite end, so that the boat can be steered from the forward end both up stream and down stream. In the tunnel the boat is lighted by electricity. The total cost of the arrangement was about £5,400, including £400 for the accumulators and £200 spent on unsuccessful trials, which latter of course could now be avoided. With the advantage of present experience the electric haulage at Pouilly could now be carried out for about £4,800, exclusive of the accumulators which are of little use: so that the cost per mile would be about £4,800 ÷ 3·75 = £1,280. The saving in cost over the old steam-tugs is considerable. During a period of six months the cost of transport over the length of 3¾ miles was 0·68*d.* per ton by electric haulage, as against 0·99*d.* by the old method, or a saving of a little over 30 per cent. The time taken is also slightly less.

Running Rope.—A third plan of towing, by means of an endless running rope working along the canal bank, was tried in France for some considerable time by M. Maurice Lévy on the St. Maur Canal, and also on the St. Maurice Canal near Charenton, where nearly every difficulty likely to occur in practice seems to have been encountered. From experiments made both in France and in Prussia it has been found that this plan is practicable, and that it will probably prove satisfactory in respect of economy. To start such a plan means of course a heavy outlay upon machinery; and to make it successful, the traffic must be frequent. The boats can be attached to the rope in a simple and ingenious way at any point along the route; and the difficulty of getting the attaching rope past the pulleys has been successfully overcome. One great difficulty which had to be surmounted was the rotation of the endless rope; this was overcome, and in 1891 the plan had been working perfectly for two years without an accident. The rope used was of steel wire, having a tensile strength of upwards of 50 tons. The supporting pulleys were placed at intervals of 230 to 262 feet apart. The two stationary engines driving the rope were each of 50 horse-power and about 15 miles apart, so that each worked a circuit corresponding with a length of about 7½ miles. The cost of traction by this plan on the St. Maurice Canal came to 0·039*d.* per ton-mile, including interest and redemption of machinery. This would point to the conclusion that, where the first outlay is warranted by the amount and nature of the traffic, the plan is not so expensive as might at first sight be expected.

On the Marne and Aisne Canal a method of traction has been in operation since the beginning of 1896, for a description of which the author is indebted to M. Bourguin, engineer-in-chief at Reims, under whose supervision the work has been executed. Since this plan has been got to work, the above experimental towage on the St. Maur and St. Maurice Canals has been discontinued. The present is the first really practical application of this plan, which is the invention of M. Maurice Lévy, to the traction of boats; and it is the only one of its kind at present at work. The total length of canal worked in this manner is only 1·37 mile, of which 1·18 mile is in tunnel, leaving in the open 0·10 mile at one end and 0·09 mile at the other. The tunnel of the Mont de Billy has so narrow a towing path that only horses accustomed to the work could get along it. As the supply of such horses was insufficient for the traffic, some other method of haulage had to be adopted; and towing by an endless running rope, which was then successfully working experimentally on the St. Maur and St. Maurice Canals, was decided upon. The work having been authorized in March 1893 was begun in June 1894, and finished twelve months later. Experiments were then made upon the new plan, and such improvements and alterations as seemed necessary were carried out. At the end of January 1896 nearly the whole of the traffic was conveyed by the rope, in order that any minor difficulties which might be experienced in the daily working of the rope might be observed and removed. On 1st May 1896 rope haulage was rendered compulsory, and has been in use successfully up to the present time. In order to get over the great difficulty of the tow line winding round the running rope, owing to the rotation of the latter, the boats are attached to the rope in the following manner. Where the attachment is to be made, a serving of twine, mixed with resin and pitch, is wound round the running rope for a length of about seven inches, forming a protecting pad; a cast-steel collar in halves is then bolted tight upon the rope, bearing hard upon the serving of twine. Against the front face of the collar bears a cast-steel saddle, which has a short coupling rope passing round it and attached to it. One end of the coupling rope terminates in a pear-shaped bulb; and the other end, which is of the same length, has a piece of rope spliced to it, with a gap or eye left for a short distance between the two splices, just long enough to allow the pear-shaped bulb to be pushed through when the rope is slack; but the gap closes tight up directly tension is put on the rope, and prevents the bulb from pulling out of it. For disengaging, all that has to be done is to slacken the rope, and the bulb can at once be pulled out of the eye. The end of the rope containing the eye terminates in a loop, to which the tow line proper is fastened. The tow lines, which are provided by the management, last a considerable time; for apart from the pull upon them in towing there is nothing to wear them out. The coupling rope round the saddle however wears out quickly, in consequence of its passing over the pulleys carrying and guiding the running rope. At the present time the running rope is in good condition, and apparently will last four or five years. The pulleys are much worn by the passage of the collars and saddles, and will require renewing about every two years. The servings of twine wear out rapidly, and have to be replaced every fortnight. The saddles on the rope have also to be renewed every few months, because, being pressed tightly against the horizontal guide-pulleys, they get out of shape and constantly break. The traffic is worked in two convoys of eight boats each way per day. For a convoy of eight boats towed against the current, which is slight, 20 horse-power is required, the speed of the running rope being about three-quarters of a mile per hour. At the end remote from the works a telephone is provided, so that notice can be given to the engine house when a convoy is despatched, and also any other instructions can be sent.

Towing by Locomotive.—The last method of traction to be considered is towing by means of a locomotive running on the bank. Some experiments on this plan were made by the Prussian government during a period of four months upon the Oder-Spree Canal, over a distance of 1·86 mile, which was purposely chosen on account of the number of windings it contained. Although up to the present no conclusive results have been obtained as to cost, yet, judging from former experience and from the calculations given, it would be too high to stand competition, even for regular and extensive traffic. In France however a service of this kind was working for several years on the Neufossé, Aire, and Deûle canals, between Les Fontinettes and the neighbourhood of Douai, over a distance of 47·8 miles with only a single lock. The locomotive was used only for going up stream; each train that it towed consisted generally of two or three fully laden barges, and the speed was about one mile per hour. But it could not compete with the horse towage service of the Deûle Canal, and was finally abandoned.

At the present time some experiments are being made upon the Bourgogne Canal with a small electric traction-engine, which runs on the towing path without rails; but in view of the failure which has always attended this method of haulage, the author thinks it will never get beyond the experimental stage, notwithstanding that it has been stated to be satisfactory thus far.

From the consideration of these four different methods of traction the author is of opinion that the only plan suitable for English canals, which are usually both shallow and narrow, is propulsion by means of screws, driven either by steam or by electric or oil motors. Haulage on a sunken chain or wire rope is quite inapplicable to the winding course of English canals; and on the Continent it is only upon long straight reaches with frequent tunnels, or where strong opposing currents are encountered, that it proves a commercial success.

Cost of Traction.—On the all-important question of cost, some plans which may be better from a mechanical point of view may be ruled out of court; while others not so good mechanically, but cheaper, succeed owing to their cheapness. In his book on the law relating to canals, Mr. Robert G. Webster, M.P., mentions the experiments made in 1882 on the Aire and Calder Canal with three modes of haulage:—namely by tugs carrying cargo; by tugs not carrying cargo and by horses. At that date towing by horses was found to be nearly seven times as expensive, and towing by tugs not carrying cargo, five times as expensive, as towing by tugs carrying cargo. Considering the great advantage possessed by mechanical traction over horse towing in point of cost, it would have been supposed that horse towing would long ago have ceased to be in general use. Such however is not the case, for even at the present time the greater portion of the work is done by horses, and on the Continent the hauling is in some instances done by men and even by women.

The cost of traction varies on every canal, and is dependent upon the regularity of the traffic, the freedom from locks, and other conditions. A method of mechanical propulsion which is remunerative on one canal might not be able to compete with horse traction on another. As an example, with the boat trains introduced upon the Aire and Calder navigation by Mr. Bartholomew the cost of traction is about the lowest that has been reached, namely 0·029*d.* per ton-mile; but, as he stated before the select committee on canals in 1883, on a navigation like that of the Leeds and Liverpool Canal the same plan would cost 0·3*d.* per ton-mile, that is to say ten times as much.

It is rather difficult to arrive at an exact basis of comparison for the cost of traction upon foreign and upon English canals, because most of the continental inland navigations are state-aided, and in some cases the cost of maintenance is borne entirely by the government, to the extent even of carrying the traffic at a loss ; and therefore the cost per ton-mile includes merely the actual cost of the haulage and whatever tolls the government may think best to put upon the canal, independently of whether it is paying or not. Whereas on our English canals the tolls have to be sufficient to ensure payment of interest, cost of maintenance, etc. In 1866 the cost of haulage by steam upon the Gloucester and Berkeley Canal was 0·077*d.* per ton-mile, while upon the Grand Junction Canal it was 0·166*d.* The difference may be traced directly to the difference in dimensions of the two canals; for while the Gloucester and Berkeley Canal is practically a ship canal, the Grand Junction is one of the shallowest in the country. According to the state engineer's report on the canals of New York State, the cost of traction upon the Erie Canal and Hudson River was as high as 0·238*d.* per ton-mile, including tolls. In his evidence before the select committee on canals in 1883 the late Mr. F. R. Conder gave the cost of transport by steam traction on Belgian canals as 0·284*d.* per ton-mile, against 0·315*d.* by horse traction ; these figures include tolls. The cost of traction by screw steamer towing three other boats on the Erie Canal was placed in 1892 by Mr. Bogart, an American engineer, at 0·082*d.* per ton-mile ; the three boats towed each carry 250 tons of cargo, and the steamer carries 180 tons. By horses towing two boats the cost comes to 0·109*d.* per ton-mile. The speed with horses is 1·6 mile per hour, while with steamers it amounts to 2·5 miles per hour.

Considering the cheapness of transport by water, it would be remarkable that the English canals are not more extensively used, were it not for the fact that most of them are in the hands of the railway companies ; or at least one or two of the junction canals which join important routes are so controlled, and upon these there are prohibitive rates in force, with the result that the traffic is kept down on the canals, and is nearly all monopolised by the railways. Even with the old mode of traction by horses it is found that minerals can be sent by canal considerably cheaper than by rail. Time is of course an important factor for general traffic, but it is not of so much consequence for minerals, for which cheapness of transport is the first consideration. On the Continent the canals are the principal means employed for the conveyance of goods; and improvements are still being carried out in the way of widening and deepening their channels for facilitating the passage of boats; whereas in this country many of the canals are choked up with weeds, and have been allowed to fall into disrepair.

In support of the assertion that even with horse traction it has been found cheaper to carry minerals by canal than by rail, it may perhaps be well to quote some evidence. There are three principal causes which render transport by canal cheaper than by railway; and they are briefly the following. First, on a canal there is no item of cost corresponding with the wear and tear of rails, sleepers, or fittings: though the cost of maintaining banks and locks must be taken into account. Second, there is a corresponding saving of the repairs required by rolling stock and locomotives in consequence of their running on a rigid permanent way. Third, the most important reason is that the maintenance of works on a canal is much less costly on an average than the corresponding

TABLE 13.—*Relative Cost of Transport by Railway and by Canal.*
See Plate 39.

Items of Cost.	Railway.	Canal.
Maintenance of way	13	0
Maintenance of works . . .	7	2·3
Repairs of rolling stock . . .	19	6
Traction	16	8
Traffic expenses	30	6
General charges	15	15
Interest on capital	100	33·3
Total . . .	200	70·6

outlay upon a railway, not only from the absence of vibration, but also from the much smaller magnitude of the works themselves. In his evidence before the select committee on canals Mr. Conder gives the accompanying Table 13 (page 183), compiled from information at his disposal, and plotted as a diagram in Plate 39, which shows the relative costs for an equal tonnage transported an equal distance by rail and by canal. It will be seen that the carriage of heavy goods by canal costs about one-third of that by railway.

In Table 14 is added a summary of the average cost per ton-mile of the different modes of traction on canals.

TABLE 14.—*Average Cost of different modes of Traction on Canals.*

Name of Canal.	Mode of Traction.	Cost per ton-mile.
		Penny.
Canal de l'Oise	Horses	0·057
Sambre Canal	do.	0·0659
St. Quentin Canal	do.	0·053
Branch Canal de l'Aisne	do.	0·0785
Canal des Ardennes	do.	0·0706
Bourgogne Canal	do.	0·078
Canals du Loing, de Briare, and du Centre	do.	0·064
Mauvage reach of canal between the Marne and the Rhine	Sunken Chain	0·052
Canalized Meuse	do.	0·168
St. Maur and St. Maurice Canals	Running Rope	0·039
Aire and Calder Navigation (tug carrying cargo, and allowing 10 per cent. for depreciation and repairs)	Boat Train	0·029
Forth and Clyde Canal	Tugs	0·143

Conclusions.– The reason why the cost of transporting goods by canal is so much cheaper than by railway lies largely in the cost of construction. Taking the average cost of the Manchester Sheffield & Lincolnshire and the Lancashire & Yorkshire Railways which was £65,700 per mile, and the cost of the Birmingham Canal which was £15,000 per mile, the former is more than four times the latter; and the cost of maintenance will be proportionately greater for the railways. In view of the smaller initial outlay on canals, and the cheapness of mechanical traction thereon as compared with horse traction, it may well be asked, why has mechanical traction upon canals in this country not come more to the front? The answer is, not that mechanical engineers are unable to design machinery to do the work cheaply and expeditiously, but that the main difficulty arises from vested interests. The all-powerful railways have by some means or other obtained the control over a portion and even in some cases over a whole network of canals. Their control over even only one section of a canal means that they control the canal throughout its entire length, together with the branches opening into it. On many canals this leads to their falling into disrepair, or to certain portions being blocked, thereby effectually preventing any through traffic. Owners who would gladly have sent large quantities of goods by canal, and would thereby have opened up a remunerative field for mechanical propulsion, have reluctantly been forced to send their goods by the quicker but more expensive railway route. Continental canals on the other hand are controlled by the government, who in the interests of the whole community at large foster this method of cheap transit; and this is the main reason why mechanical propulsion on canals is more widely developed on the Continent than in our own country. The cause of the non-success of mechanical propulsion in this country may clearly be considered to be beyond the forces which can be controlled by mechanical engineers.

The best method of mechanical propulsion for our own country, on canals which are still in the hands of private owners, must undoubtedly be that which necessitates the least alteration to the existing boats and canals in their present conditions, so as to be applicable to the boats in their present form, without structural alterations, and without in any way preventing them from passing through existing locks. The machinery should occupy as little weight and space as possible, and should be of simple construction and capable of being managed by an ordinary bargeman; the cost of first outlay and of maintenance must be small; and last but not least, the cost of traction per ton-mile must be as low as possible. As to the best form of boat to be used on any canal, and its relation to the wetted section of the canal, the author hopes that, as soon as the experiments of M. de Mas on this subject are published, the mathematical and theoretical side of the problem will be satisfactorily settled. In conclusion he wishes to convey his best thanks to the gentlemen who have so kindly placed the results of their valuable experiments at his disposal, notably MM. de Mas, Hirsch, Galliot, Sir William Bailey, Mr. Wilkinson, Mr. Ellis, and others; and also to his assistant, Mr. Charles Dresser, for his co-operation in the preparation of this paper, which he trusts will be found to contain information of some service to members of this Institution who are interested in the subject of mechanical propulsion on canals.

Discussion.

Mr. Robinson said the subject of canal-boat propulsion in canals was so large that he had been compelled to confine the paper as far as possible to this, and to say but little about experiments upon propulsion in rivers.

In Table 7 and the corresponding diagram, Plate 32, a point was illustrated which he thought had not been brought out quite so prominently before, namely how far the resistance to traction was independent of the length of the boat. It would be seen that although the *Alma* was nearly double the length of the *Adrien*, yet the curve of resistance to traction was almost identical at all the five speeds tried; and for the *Alma* and *René* the same was true, not only with the draught of 5¼ feet, but also with 1 foot less draught. This result seemed altogether contrary to what would have been expected; and it was certainly contrary to what would take place in an unconfined expanse of water. Many of the results obtained therefore must be dealt with, not upon the basis of open water, but in view of the conditions under which boats were working in the confined channel of a canal.

Another point that had been brought out clearly was shown in the diagram of Table 10, Plate 34, where it would be seen that, while the ratio of the section of waterway in the river Seine to the midship section of the boat dropped as much as from 116 down to 72½, the resistance increased only from 26½ lbs. up to 28¾ lbs., on account of the wetted section of the river being so large in proportion to the midship section of the boat. But when the same boat came into a canal the difference was at once clearly seen: while the ratio of sections dropped only from about 4⅛ down to 2⅞, the resistance ran up from 37½ lbs. to nearly 73 lbs., owing entirely to the restricted channel in which the boat was moving.

Another important point was that illustrated in the diagram of Table 11, Plate 38, where the effect of the distance between the bottom of the boat and the bed of the canal was brought prominently into notice. Here the plotted curve, representing in a sense the resistance, dropped quickly to begin with, and afterwards fell away more slowly as the depth of water beneath the boat increased. It need hardly be pointed out that the practical bearing of this observation was that, in determining the size of the boat in relation to the depth of the canal, there was a certain point beyond which it was not economical to increase the draught. These particular observations in Table 11 might perhaps by some engineers be considered rather far-fetched; yet in their bearing upon the size of the boat and the depth of the canal they possessed some importance.

With regard to the question of the injury to the canal banks, he wished to draw attention to the fact that the highly interesting experiments carried out by Dr. Pole had been confirmed over and over again, showing that with a speed exceeding about three miles per hour destructive effects were produced upon the banks, the injury extending about one foot above and one foot below the water line. This again was entirely due to the restricted section of the channel.

Sir E. LEADER WILLIAMS considered the diagrams representing graphically the tables given by the author would be of great interest to everyone identified with canals. His own life having been spent almost entirely in connection with canal navigation, he had followed

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the paper with a great deal of interest. Just as on railways, notwithstanding improvements in locomotives or rolling stock, no progress could be made unless there was a good permanent way, so on canals the importance of a good section of channel had been brought out clearly in the paper by many examples. When designing the sections for the Manchester Ship Canal he had not followed the French normal section shown in Plate 37, because he had not that section in his mind at the time, although no doubt it had already been published; for it seemed obvious to him, after having so long studied the subject, that the nearer the cross section of a canal could be brought to a rectangle the better. In the French normal section there were seen to be slopes of 1½ to 1; and with the section of boat shown as that used on the French canals it was evident that there would be ample room for two boats to pass, leaving a good waterway between. But the slopes shown could not be kept up unless they were protected by stone, particularly where there was steam traffic. The damage to the canal bank had been stated in page 164 to extend probably through a range of only about 2 feet, half above and half below water-level, which was no doubt correct in the case of horse traction; but the same statement did not apply where there was steam propulsion. When two boats passed, even if they each had only one screw instead of twin screws, the screw came nearer to the bank, and revolving at a high velocity it scooped away some of the slope. This result had been clearly ascertained from the effects observed on the Bridgewater Canal, on which the slopes of the banks had originally been made about 1½ to 1 through hard boulder clay and material of that sort, and somewhat flatter through softer ground. At the time when he first went to that canal there was severe competition with the railways; and in consequence of disease occurring among the three hundred horses employed on the tow-path, about two hundred of them had to be killed. There was therefore no alternative but to employ steam power; and on looking back he had found that steam had previously been tried on the Bridgewater Canal over and over again, but had always failed. The first book he had met with on the subject of steam power on canals was by Sir William Fairbairn, and was dated

1831. In it were recorded some interesting experiments, as the result of which he did not see why steam propulsion should not be used. The first boat he built was a tug-boat about 61 feet long and 8 feet beam, into which was put a multitubular locomotive boiler and an ordinary portable engine by Messrs. Marshall of Gainsborough; it had a single 12-inch cylinder with 16 inches stroke, working with 80 lbs. steam pressure and at about 100 revolutions per minute. The screw was 3 feet 3 inches diameter, which at that speed would have been of little use, as a higher velocity was needed. The question was whether to drive the engine faster for working direct, as was so much the fashion now on other navigations, or to get up speed by gearing. The objection to the latter was that it was far noisier; but by the simple plan of using wood and iron teeth running together, he had secured the speed while minimising the noise. On a narrow canal, where the screws were apt to get foul of the banks, it was an advantage to have gearing, because it partly took the shock away, and prevented greater damage. If a breakage occurred of the gearing, it was an easy thing to put a fresh wood tooth in; if the engines broke down it was a more serious matter. The result had been a perfect success. Although the tug-boat was not able at first to tow more than two or sometimes three flats, each conveying 40 tons of goods, yet even at that rate, in comparison with the cost of the horses, the working expenses were reduced by 54 per cent.; and there were now twenty tugs constantly at work.

This was the bright side of the picture; but he had not expected to get off without something on the dark side. Wherever two tugs happened to pass, the slopes, which while the barges were towed by horses had stood fairly well at 1½ to 1 or 2 to 1, began to be scooped out below by the wash from the screws, and then began to fall in above at the water line. On the opposite side to the tow-path this gradual degradation of the bank did not much matter, because it was agricultural land for which compensation could be paid when the bank had settled down to its natural slope in course of time. But on the tow-path side the damage of the bank was a more serious affair, the occurrence of which seemed to him to present a good opportunity for improving the canal. For while the tow-path had

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to be kept in a state of efficiency for the ordinary traffic, it was soon found that a larger sectional area would enable more work to be done with the steam-tugs, and at the same cost. Besides the traffic belonging to the Bridgewater Canal proper, there was a large through traffic from other navigations, which necessitated a sufficient amount of elasticity in the arrangements to accommodate the variety of boats that had to be towed. On his recommendation it had therefore been decided to put in a nearly vertical wall on the tow-path side, as shown in Plate 45, which was rather a heavy job for thirty miles of canal. Along certain short lengths of the path the same thing had previously been done on a small scale and to a less depth; but this damage done to the slope by the tugs had brought all the old wall down in ruins. The whole length of the tow-path was not walled afresh, as in some places it was cheaper to pile and to dredge out the stuff in front of the piles, as was done also on the agricultural side to a smaller extent. The change in the section of the canal would at once be seen from the dotted line in Plate 45, representing the old bottom at an average depth of only 4½ feet, which had now been dredged to a depth of 6 feet for about a third of the width. The result was that the same tugs now towed four barges, each carrying not 35 or 40 tons, but 50 tons easily, making 200 tons total, at 2¾ miles an hour. The thirty miles distance from Runcorn to Manchester was done in ten or eleven hours. The consequence of that work had been not only a large saving in the cost of towage, but the canal had become master of the traffic in a way it had not before been. Formerly there had been employed on the tow-path men whose character was such that they could get no other work; and four horses had to be used for towing one flat, two horses taking the first fifteen miles of the journey, and two more the other fifteen. On that plan there was no controlling the traffic; and in competition with the railways the canal could not get on. Now the whole work was carried on in railway fashion. The whole of the barges were taken four together by the tug, upon which was put a competent man at good wages, with a premium for keeping good time. The barges were obliged to follow the tug, and the men in the barges had only to steer; there was no bother about anything else. This illustration therefore served well to show the importance of a good section of canal: it was the foundation of the whole work.

Another example in his own experience was on the Weaver Navigation, where he had carried out some extensive works. When he went there in 1852 the salt traffic from Winsford northward was taken down the River Weaver navigation to Liverpool by a pair of horses towing a flat which carried about 80 tons. The Weaver trustees gave him large powers for improving and developing the navigation; they were in the fortunate position of having no shareholders, and no debts, enjoying a large surplus revenue of £50,000 to £60,000 a year, of which the county of Chester had the benefit of about half. A great deal of the remainder was spent by himself without troubling contractors, with the result that the river was much improved and deepened, the locks were made larger, and irrespective of steam-power one horse could easily tow a barge of 150 tons, as against two horses previously towing together only 80 tons. Later on he carried out still larger works, with the result that at the present day the salt was taken from Northwich to Liverpool by steam-power, in a large barge with a small engine, and a screw astern, carrying 250 tons. She not only took her own cargo, but towed two other barges, each carrying from 150 to 200 tons. The locks were made larger, in order to let the whole fleet pass through at once. There was now no railway that carried a ton of salt from Cheshire to Liverpool or Birkenhead: there was no competition for traffic of that sort; it was carried wholly by water. There was a further advantage in water carriage of this kind. Each of the flats became a floating warehouse, going alongside one ship after another in the Mersey docks, and able to follow any ship if she changed dock. This was an advantage to the port of Liverpool, because it did away with salt wagons forming an obstruction all over the quays.

His experiments with a wire rope on the Bridgewater Canal had been mentioned in the paper (page 174). Having found that a chain or wire rope had been used with considerable success in Belgium, and having experienced so large an amount of slip of the screw in the canal, especially before the section was altered, it had seemed to him obvious that a wire rope making two or three turns round a drum driven by steam-power would do away with the objection of slip of the screw. That conclusion was sound enough as far as it went; and on a straight length of canal, where there was no mixed traffic, the plan was a great success, and there was no doubt that it was the best mode of propulsion. But unfortunately canals could not be made straight. Fortunately indeed in another sense Brindley had not made the Bridgewater Canal straight, but had carried it at one level from Runcorn to Manchester without a lock, whereby it had been put in a position for steam traffic that no other canal was in. It had purposely been carried out so as to follow the contour lines of the country, and to avoid locks; and as the curves were consequently so numerous, the whole question of wire-rope towing had thereby been practically settled beforehand. For in rounding the curves it was impossible to help bringing the rope tight round the inner side of the curve. Where there was a straight reach, and the rope was fast at the end of it, the pull was all straight; but where there was a curve and a train of barges, the rope got pulled obliquely across the waterway, and thereby impeded the other traffic passing by. A good deal of money had been spent in trying the plan; but it had had to be given up, and steam-tugs to be reverted to.

There was a great future he thought for electricity on canals. Many people did not like to see wires and trolleys working over a street, as in America and elsewhere; but on a canal it would not be so objectionable. On many canals he was of opinion that electricity might be used with considerable advantage, provided that care were taken not to interfere with other traffic which would probably not use it.

The Aire and Calder Navigation, with which he was familiar, was a canalized river, and therefore full of windings. The trains working with the tug ahead he had not seen, as the tug was astern when he made some trips on it. The steering was done as described in the paper (page 169), by a wire rope along each side of the train, worked by a cylinder; and when the train came to a bend, instead of putting the helm over and twisting the boats round, the steersman merely slackened the rope on the outer side and tightened it on the inner, thereby curving the train conformably with the radius of the bend, so that it went freely round the curve. On the Mississippi a similar plan was being carried out, on a scale which, when he first heard of it, he hardly believed. There were large stern-wheel steamers on that river, going from the collieries up above down to New Orleans, each of which pushed a huge mass of lighters laden with coal, not actually arranged as a long train, but compacted all together into a block, like the timber rafts. A central space was left astern, equal to half the steamer's length, in which she took up her position, and pushed the whole block. In that way as much as 40,000 tons of coal in a block had been pushed down the river with the current—not up—by one steamer; it was the largest convoy he knew of in inland navigation. Great difficulties were of course experienced. The upper tributaries of the river could be worked only in times of freshets. When there was a good freshet coming down, the block of lighters got ready to start. Sometimes portions of the block got left aground; but this did not seem to trouble the owners. For as timber was cheap up the river and was worth something in New Orleans, the lighters were built cheaply, merely like rough boxes; and if one or two were lost, no one seemed to care much about them. When they got to New Orleans, it simply depended upon what price could be got for the timber, whether the lighters or boxes should be taken back again or not. It seemed to him an interesting and peculiar procedure, such as he had not met with previously in the course of a somewhat long life spent in dealing with inland navigation.

Mr. **Arthur D. Ellis** said that for the experiments in which he had taken part on the Leeds and Liverpool Canal (page 172) the centrifugal pump for hydraulic propulsion had been specially designed by Mr. Capell, whose name was identified with ventilating fans having the peculiar form of vanes that had been devised by him; and the same form had been adhered to in the hydraulic pump employed for the propulsion of the boat illustrated in Plate 40. Mr. Capell's own experiments on the application of his fan to

(Mr. Arthur D. Ellis.)

hydraulic propulsion had been begun on the River Ouse, near his residence at Passenham in Northamptonshire, and had been carried out there with some success. Unfortunately however, the river being more or less torrential, it had not been practicable to ascertain accurately the speed of the boat and the horse-power expended in propelling her ahead and astern up and down the river, because the force of the currents could not conveniently be measured. The experiments were therefore transferred to the Leeds and Liverpool Canal, where a stretch of about a mile was taken along the biggest section of the canal, which was about 30 feet wide and 6 feet deep. The new boat shown in Plate 40 was designed and built by Messrs. Yarrow, for which the screw and boiler were designed and made by Messrs. Plenty and Son of Newbury. The first experiments consisted in running the boat up to her utmost speed with the screw, and indicating the engine thoroughly, so as to find out precisely what she could do as the maximum; the result was shown by the line SS plotted in the diagram, Fig. 13, Plate 44. The screw was then taken out and replaced by Mr. Capell's special turbine for hydraulic propulsion, and the result was again plotted as shown by the curve CC. In this way the fact was arrived at, which he believed had never before been brought to light in hydraulic propulsion: namely that at the speed of about $2\frac{3}{4}$ miles an hour the boat could be driven by the same horse-power with hydraulic propulsion as with the screw. It must be borne in mind that $2\frac{3}{4}$ miles per hour on a canal was about equivalent to six or seven miles an hour in open water. Previous results of hydraulic propulsion had been published in the Proceedings of the Institution of Civil Engineers (1884, vol. lxxvii, page 1) in connection with Mr. Ruthven's "Waterwitch" and a torpedo-boat built by Messrs. Thornycroft. Those vessels were of course much larger than the experimental canal-boat shown in Plate 40; but comparing tonnage and horse-power he believed it would be found that the results obtained on the Leeds and Liverpool Canal with Mr. Capell's form of vanes, and also with his form of discharge orifice on which a good deal of stress was to be laid, were highly remarkable in the history of hydraulic propulsion. The experiments had been interrupted, because unfortunately the canal would not admit of a bigger boat; and moreover it was not convenient at the time to go a step further, as undoubtedly ought to have been done. At some future time however he hoped a larger boat would be built of some 50 or 60 tons burden, and the experiment be tried in open water. In the present experiments, which he thought were the most recent in hydraulic propulsion, it had been found that, with a speed equivalent to six or seven miles an hour in open water, the same economy had been obtained by the hydraulic propeller as by the screw. The numerous tests had all been carefully made by Mr. W. B. Crichton, by whom the diagrams in Plate 44 had been drawn up; and the best results had also been repeated in the presence of Mr. Charles White, the engineer of the Leeds and Liverpool Canal. The scoops mentioned in connection with some of the curves in Plate 44 were scoops placed on the bottom of the boat, behind the inlet to the hydraulic turbine, with the idea of getting a better flow of water through the turbine.

With regard to the form of nozzle employed, the boat had been tried without nozzles at varying speeds from $4\frac{1}{2}$ to $5\frac{1}{4}$ miles an hour, as shown by the curve DD, Fig. 13, Plate 44; but the power required was about 27 per cent. more than with the nozzles. As soon as the nozzles had been put on, a speed of $2\frac{3}{4}$ miles an hour was obtained in the canal with the same horse-power as with the screw. The nozzles were thus the secret of the success.

Rev. G. M. CAPELL said that, having in boyhood made a great many experiments upon screw propulsion in a steam launch, it had been suggested to him that propulsion by a turbine was useful in open water, and probably might be so in a canal; and he had accordingly carried out his experiments in the river close to his house, with a form of a turbine which he had designed to pass a large quantity of water. As the river was a mill head, it was difficult to get a steady trial except when the mill was not running, which was seldom. The turbine was 11 inches diameter, and when driven at 650 revolutions per minute it would pass five tons of water per minute. It was put into a boat 30 feet long and 6 feet beam, for which unfortunately the boiler was too heavy, so that when the boat

(Rev. G. M. Capell.)

was loaded the weight was exactly 5½ tons. With the use of one nozzle a speed of seven miles an hour was obtained on the river when going down stream with little current. The effect of the partly constricted jet nozzle was remarkable. Before the nozzle was put on, several runs were made with 125 lbs. pressure of steam, the discharge orifice being 6 inches diameter. The turbine was driven by an engine of his own design, shown in Fig. 9, Plate 42, which had an oscillating diaphragm piston making a quarter turn between fixed abutments; power was given to the crank through a lever and connecting-rod in the usual way. It was difficult to indicate, and therefore the power had to be worked out approximately from the steam-pressure and the combined area of the two rectangular pistons, which was exactly 12 square inches; the stroke was 5½ inches. With 125 lbs. steam-pressure and no nozzle on, a speed was obtained of six miles an hour over a measured distance of a little more than 650 yards of straight run. With the first nozzle that was tried the steam-pressure was brought down for the same speed to 105 lbs. With further improvement of the nozzle it was found that with 95 lbs. steam-pressure the boat could do what it had previously been doing with 125 lbs. per square inch; and at the higher speed of 750 revolutions of the turbine per minute a boat speed of seven miles an hour was obtained. The form of the nozzle was peculiar in the effect which it had upon the jet of water discharged. When the boat was tied to the bank, and the distance measured astern at which the water of the jet would turn up at surface, it was found to be about 45 feet when the water was discharged full bore from the 6-inch pipe without the nozzle on. When the nozzle was on, the water went aft in a clean compact jet, like a Whitehead torpedo running under water, to a distance of 90 feet, and then turned up at the surface. The principal result therefore of this experiment was that on the form of the nozzle or discharge orifice would depend the efficiency of propulsion. Other experiments had been tried which were interesting, with the boat pulling against a spring balance. On measuring the pressure of the issuing water by means of a mercurial gauge, a curious result was arrived at, which was repeated over and over again: namely that the propelling force of the jet, measured by a mercurial gauge placed close behind the discharge orifice, represented altogether only 68 lbs. total pressure, while at the same time the spring balance showed a pull of 125 lbs. This was a phenomenon which he had never been able to explain; but it could be repeated at any future time, whenever the subject became more fully understood. One thing which had been established most completely in these experiments in the river was that with the jet the wake of the boat was as quiet as could possibly be; there was no disturbance of any kind in the water immediately astern, because the turn up of the jet to the surface was a long way aft, and the wake did not the least resemble that of a boat propelled by a screw. It seemed a pity that the experiments had not been carried further, but he had not had time to spend in making them more complete; and he should much have liked to see them carried out on a larger scale. What had been thus far arrived at was that, where an efficiency was obtained with hydraulic propulsion which compared well with that of the screw, it resulted from the particular velocity of the water through the turbine, in conjunction with the nozzle described above; and he was confident that, if it could be managed to make the water flow through the turbine at about the speed which was found the best, there was no reason why the hydraulic propeller should not become a most useful instrument for the propulsion of large ships, as well as in experimental boats. At very high velocity of flow the efficiency fell rapidly.

Mr. Henry Barcroft had noticed with a great deal of interest that the first part of the paper, dealing with the theoretical aspect of the subject, showed how true it was that so far no satisfactory formula had been promulgated for the efficiency of any particular mode of propulsion; and he supposed it had not yet been arrived at. In nearly all the author's comments upon the formula ordinarily employed, he wound up by saying that it was not quite reliable. In Table 7 and the corresponding diagram, Plate 32, where the lengths of three boats were very different, it appeared that the resistance was nearly the same for all three. On the other hand, in

(Mr. Henry Barcroft.)

page 166, there was another illustration in which two boats seemed closely alike, excepting a slight difference in build; and yet their resistance was widely different. It occurred to him therefore that some further explanation might be acceptable with regard to the great difference in the results under what seemed so nearly similar conditions.

Leaving the theoretical part of the subject, he had been much struck with what Sir Leader Williams had said (pages 188–192) with regard to the Bridgewater Canal and the advantage of having on it some mode of mechanical haulage, perhaps electrical, or perhaps by rope, or perhaps by steam-tug. At the same time it had also been explained that the boats travelling along the Bridgewater Canal came from a variety of other navigations, and were collected on the canal as on a sort of trunk line, and were then dispersed in various directions. It therefore appeared to himself that the method which might be thought most desirable for the Bridgewater Canal would not be equally available for the several boats in the earlier and in the later part of their voyages. He thought therefore that the principles laid down by the author in page 185 were really those which should govern the question of canal-boat propulsion, considered apart from ordinary propulsion on rivers or in open water: namely that the most successful method would be that which should be applicable to existing boats working on existing canals and passing through existing locks. Where these conditions had to be adhered to, a great many of the plans which had been described would not be at all available. Mention had been made (pages 149 and 171–2) of the propellers which he had described at previous meetings; and these large-bladed propellers partially immersed he thought did meet the requirements. The boat could not only commence her voyage, but could continue and terminate it, by the same method of propulsion. No longer ago than yesterday he had seen one of these boats laden with 500 barrels of oysters, which she had taken on board from a steamer and was about to deliver at the oyster beds along the sea coast. The different navigations she had to pass through for this purpose were such that only an independent method of propulsion would be available. Horses could not take her to the places she was going to. One of the features was that no other boats of the same dimensions could possibly carry one barrel more than she had on board; and he did not know of any other steamer that could carry so many. Taking for instance the vessel represented in Plate 40, it would be observed that the middle of the hold was occupied with machinery, which took up a large amount of space that could otherwise be filled with cargo. In the boat which he had seen yesterday there was no machinery whatever inside; all the deck space and the entire hold were filled with oyster barrels, and yet she was able to go on her voyage without any inconvenience. This he thought was one of the chief points in canal-boat propulsion —economy of space, and economy of weight.

Mr. Bryan Donkin, Member of Council, asked where the nozzles were placed in the experiments on hydraulic propulsion described in the paper (page 173), and what was their particular object. Also in addition to the data given by the author, had he found any German or Swedish experiments bearing upon the subject of the paper?

Mr. Ellis replied that the nozzles were affixed to the discharge orifices of the hydraulic turbine, and by their addition it was enabled to develop a much better propelling power. The reduction in area of passage through the nozzle he believed was about 33 per cent. In the experimental boat tried at Skipton, the two discharge pipes themselves were each 5½ inches diameter, and the nozzles were of the shape shown in longitudinal section in Fig. 12, Plate 43; for the contraction of 33 per cent. the curve forming the outline of the contracted length was an arc of a circle of the same diameter as the discharge pipe, namely 5½ inches. If the contraction of area in the nozzle was either much less or much greater than 33 per cent., in either case an inferior result was obtained. The stern of the boat was arranged like that of a twin-screw boat. If a new hydraulic boat were to be built, he should recommend doing away with the stern post and the big breeches-pipe, and altering the construction so as to discharge the water in a single central jet. The boat shown in Plate 40 had not been designed for carrying any cargo; but

(Mr. Arthur D. Ellis.)

the actual space which the hydraulic machinery took up as compared with a screw he thought was not much greater. Had the experimental boat been originally designed independently for hydraulic propulsion, and not as a compromise based upon a pre-existing screw-propeller which went through the keel and came out at the stern, there would have been only a single central discharge-pipe about 8 inches diameter, and it would not have taken up any more room than the propeller shaft with its couplings on. The engine was the same engine in each case, so that the hydraulic machinery would not have taken up any more space than the screw arrangement. The discharge pipes all ran under the deck, in places where no cargo was carried. The draught of the experimental boat when fitted with the hydraulic apparatus was little greater than with the screw propeller.

Mr. BARCROFT drew attention to the fact that in the lighter which he had mentioned as laden with barrels of oysters, and in similar boats fitted with his large-bladed propellers, there was no machinery at all inside the boat: the whole of it was on the outside.

Rev. G. M. CAPELL, in explanation of the action of the nozzle upon the jet discharged from the hydraulic turbine, pointed out that in the absence of the nozzle the jet issuing from the plain pipe naturally assumed the form so well known as the *vena contracta;* and in doing so it carried along with it in the contracted portion of the jet a body of external water in an induced current, which to a certain extent interfered with and obstructed the free flow from the pipe. In his experiments he had therefore tried a peculiar form of nozzle, conforming to the natural shape of the jet and enclosing it on all sides, thereby preventing any external water from being carried along with the jet. The principle was the same that he had adopted in the *évasé* or expanding nozzle of the Capell ventilating fan, which had been largely improved by that means. In each instance an increase of useful effect was realised by preventing the external air or external water from interfering with the free discharge of the issuing jet. In his own experiments the discharge pipe was a single copper tube running straight aft from the turbine. The stern post was cut away to let it pass centrally, as shown in Fig. 10, Plate 43, and two side clips embracing the copper tube were riveted to the sides of the stern post above and below the tube, which was thus secured exactly like a large propeller-shaft. That made a good solid job. The hydraulic propeller was like a double turbine, one inside the other, as shown in Plate 41 and in Fig. 8, Plate 42, having a form of blades which was a modification of that employed in the ventilating fan. The angle of the outer blades was varied according to the speed at which the turbine had to be driven. Lately the form had been still further modified, thereby producing a still higher result in moving large bodies of water. In his first turbine boat the water was taken in through a pair of channels brought up from the bottom of the boat, one on each side of the turbine, as shown in Fig. 10, Plate 43; and this was the arrangement he had found best in his experiments. It had one disadvantage however, that if the engine ran too fast there was a tendency to sink the boat, when so heavily laden as in these trials. On two occasions it had been nearly swamped by the inflow pulling the boat almost under water; if the engine had not been stopped instantly, she would have gone right under. That was the only disadvantage he knew of in taking the water in from underneath the boat in that way, which could easily be obviated in future arrangement of weights. The experiments had certainly been useful in proving that, the shorter the inlet could be made to the turbine, the better. They had also proved that, the more direct the discharge from the blades of the turbine, the more certainly would an economical result be obtained; a breeches pipe caused great friction and loss.

Mr. J. Hartley Wicksteed, Vice-President, observed that mention had been made in page 169 of the Aire and Calder Navigation and the trains of articulated boats, which, residing as he did in that district, he had had opportunities of seeing. They were not always pushed from behind; at the present time he believed they were pulled from the front. Moreover they were not now tied with wire-ropes from end to end, so as to occasion any difficulty in

(Mr. J. Hartley Wicksteed.)

separating the train; the successive boats were just lashed together, each to the one in front and to the one behind, so that it was easy to divide a long train at any part in order to send it in two detachments through locks. Each boat was sloped off at a blunt angle in plan at each end; and at the apex of the angle was a central half-round projecting knuckle or stem at one end, and at the other end a corresponding half-round hollow or vertical notch, into which fitted loosely the knuckle on the end of the next boat; and the blunt angles of the ends of the boats left space enough between them for enabling them to take a curve. There were buffers at the extreme width on each side, to protect the boat ends from damage when they closed up against each other in bending round a curve; and in line with the buffers were upright square posts or bollard heads standing up above the gunwale. A light chain or rope was just wound two or three times round the post on one boat and the adjoining post on the next boat, tying them together with a certain degree of tightness which could be humoured as might be found desirable.

The diagram, Plate 32, showed that the length of the boat did not increase the resistance; and going still further it appeared that in these long articulated trains of boats the **V** shaped gaps or gaping spaces, where the water could get in between the ends of adjoining boats, did not increase the resistance perceptibly. The water in the gaps was carried along in some way or other with the train; there was no great eddy formed at the gaps, and the outside water did not get far inside the gaping space, which did not seem to present much obstruction, so that it was not worth while trying to cover it in by a leather flap or anything of that sort. The advantage of having the boats coupled up in so simple a way was that each could be readily detached from the train and floated separately into a cradle, which was lifted by a hydraulic lift and then tilted over, so that the whole contents of each boat of a train were discharged almost instantly into a ship, and the loading of a vessel with coal was thus extremely quick.

In the present paper a strong motive had come out for the broad propeller-blades advocated in Mr. Barcroft's paper at the previous meeting; because it appeared in page 165 that the experience on the North Holland Canal which went to Amsterdam was that the wash was increased when the propeller revolved at more than a certain speed, independently of the progress made by the boat. This he thought showed that the waves which destroyed the bank were not altogether caused by the displacement of the boat, but partly by the action of the propeller.

Mr. W. G. WALKER pointed out that, if the resistance to traction was entirely independent of the length of the boat, as stated in page 154–5, it would follow that, no matter what the tonnage of the boat might be, the resistance would be the same. This seemed indeed to be the case in the experiments cited, in which two boats differing in their tonnage, one of 148 and the other of 286 tons, showed nevertheless exactly the same resistance. It was difficult to believe that in lengthening the boat the stream lines or ship-shape section of the boat had been improved to such an extent as to cause the resistance to remain the same although the tonnage was nearly doubled. The greater amount of the resistance arose from the skin friction of the boat. This subject had been fully investigated twenty years ago by the late Mr. William Froude, by whom the total resistance had been divided into three parts: that due to skin friction; that due to eddy; and that due to wave. For a well designed boat, that due to eddy was practically nothing, and that due to wave was only 10 per cent. of that due to skin friction; and at slow speeds the whole power was practically spent in the skin friction. In the above example the skin resistance must have been largely increased by making the boat longer; and even taking into account any improvement which might have occurred in the lines, it was difficult to see how the total resistance could fail to be increased also. Another point, to which attention had been drawn in page 152, was that the resistance did not vary as the square of the speed. This was now well known to be the fact; progressive speed trials had shown that the horse-power did not vary as the speed cubed. In this connection examples had been given in Table 2 of observed and calculated resistances, showing that the calculated differed to a material extent from the observed. Here it would be seen that the value of the constant coefficient K for the calculated resistance had

(Mr. W. G. Walker.)

been taken from the slowest speed of the boat at each draught. It appeared to him however that it would have been better, had the constant been taken from the mean speed. The trim of the boat might have varied to a considerable extent from the lowest to the highest speed; and any slight error, which might easily creep in at a slow speed, would be multiplied to a considerable extent if the constant were taken from the slowest speed. The variation in the trim of a ship, which was noticed during progressive speed trials, might assist to account for the fact that the horse-power did not vary as the cube of the speed.

In reference to the depth and width of channel, he agreed in the main with the views expressed in the paper. During 1891 he had carried out many experiments upon this point, and some of the results had been published in his paper on screw-propeller surface in 1892 (Proceedings, page 514). Those experiments had been carried out on the Avon near Bristol, at two places where the cross sectional area of the stream was nearly the same at each, while the width and depth varied; and under the conditions in which the experiments were tried, the width of the stream appeared to possess much greater importance than the depth. The earliest of the experiments on the Avon had been carried out at a part where the width was 50 feet. The later had been made higher up the river, where it was 100 feet wide, the wetted cross section of the stream remaining the same; and here the greater width had enabled half a knot more to be obtained with the same horse-power. The depth did not affect the result nearly so much; this was made obvious in passing through a lock, where the width was diminished to a considerable extent, while the depth was the same or even greater than in the main stream. In those experiments the speed went up as high as eight miles an hour, at which it would readily be understood that the wave would be excessive. It swept over the tow-path, and washed the banks to such an extent that there was great difficulty in obtaining permission to complete the experiments.

Mr. E. C. DE SEGUNDO was glad to hear from Sir E. Leader Williams a word in favour of electric traction on canals (page 192).

Already a good deal had been done in that direction, as shown in the paper; and in America a concession had now been obtained for utilising on canals the electric power generated at Niagara Falls. The great advantage of electric power lay in the fact that it was so elastic in transmission and application; so many things could be done with it which could not be done as easily with mechanical power. It could often be dealt with in a much simpler manner than mechanical power; and if it could only be produced at a low enough cost, it was in many ways a most desirable form in which to produce power. The question of cost was naturally governed by the means at disposal for producing electricity. In a canal there was a considerable amount of water which of necessity must at certain points run to waste over the weirs. If the conditions were favourable, the water which now ran to waste might be utilised and converted into power available for traction. In travelling not only in England but on the Continent he had noticed that there were many canals upon which electric traction might be advantageously applied by utilising water which at present ran to waste. Notably in Scotland there occurred on the Crinan Canal a close succession of six locks, indicating a rapid and considerable fall, which possibly might be utilised if the amount of traffic were sufficient to render it a remunerative undertaking.

Upon the important question of railway control, there was clearly a good deal to be said both for and against it. If canals were taken over by the government and made to serve the country, instead of the country serving the canals or the railways as it now did, the cost of the transport of goods would no doubt be much reduced in some cases. But having regard to the large capital now invested in railways, little practical result was to be anticipated from efforts to substitute water carriage for railway carriage in England. Possibly some middle course might be advantageously pursued under special conditions; but it appeared to him that energy would be better applied to getting the railways to reduce their rates.

The remarkable fact brought under notice in Table 7, that the same tractive power sufficed to pull a boat which was twice as long as another and carrying twice the load, led him to imagine that in

(Mr. E. C. de Segundo.)

some way or other these particular experiments must have been made under peculiar conditions. Having regard to the diagram in Plate 34, where it was seen that in the canal a small diminution in the ratio of the wetted cross section of the waterway to the immersed midship section of the boat brought about such a large increase of resistance, it seemed possible that something of the sort might have occurred in connection with Table 7, and might just have counterbalanced whatever increase in tractive force might otherwise under similar or identical circumstances have been required by the longer boats. This most important point he hoped would be further gone into, having so close a connection with the cost per ton per mile of canal traction.

Mr. J. Macfarlane Gray enquired the basis upon which the cost of traction was stated in the paper: were the wages included, or only the fuel?

With regard to the ratio adopted throughout the paper, of the wetted cross section of the canal to the immersed midship section of the boat, which appeared not to give a satisfactory result, it seemed to him that it ought not to be the ratio of the full section of the canal to the section of the boat. For while the boat was going in one direction, there must be an equal delivery of water in the opposite direction, passing backwards along the sides of the boat. The sectional area through which the water was passing backwards alongside the boat was not the whole section of the canal; it was the full section diminished by the section of the boat. This altered the ratio by subtracting 1 from it. If in the form employed in the paper the ratio was 7 to 1, it ought properly to have 1 taken from it, and then it became 6 to 1. He wished to express his high appreciation of the paper, which showed how ably such a difficult subject could be dealt with.

Professor Robert H. Smith thought that, although an algebraic change in the shape given to the formula was required, it did not make much actual difference whether the ratio used were that of the whole wetted cross section of the canal to the immersed midship section of the boat, or that of the cross section of the canal diminished by the cross section of the boat to the same immersed boat section. A much more important difference he suggested would be made, if, instead of the ratio of these sections to each other, the ratio were taken which the net water section left by the immersed boat bore to the joint wetted periphery of the canal and boat together: the latter ratio would denote the mean hydraulic depth of the water section left between the boat and the canal banks and bed. Upon this principle, and using the ordinary rules for the flow of water through narrow rough channels, he had recently made a calculation of the horse-power required to drive canal boats; and it had been found that the horse-power so calculated came within 5 to 8 per cent. of that which had been prescribed by one of the most experienced shipbuilders as necessary for the service required.

Mr. W. WORBY BEAUMONT considered what Mr. Macfarlane Gray had said (page 206) concerning the ratio of the sections was not only correct but highly important. For in the imaginary extreme case where the barge and the canal were of the same section, or at all events an easy fit, it would be seen that the ratio employed in the paper would then be represented by 1; whereas if 1 were taken from this, as it ought to be, the true ratio for the comparative purposes of the calculations and tables in the paper became 0. Recently he had been travelling for five days on the Grand Junction Canal from Brentford to Northampton in the excellently designed boat of Mr. H. R. de Salis, built expressly for inspection purposes, with engine and machinery all new and in good condition; and on no part of the canal could a speed be attained of more than about 5½ miles an hour. It was exceedingly interesting to watch the variation in speed of the boat and the corresponding variation in speed of the engine, which took place conformably with the variation in the section of the canal. In some places, such as those under bridges where the tow-path had to encroach upon the width of the canal for some length, or wherever the virtual section of the canal was reduced by passing another boat, the extra work necessarily thrown upon the propeller, for pulling the water from the front and

(Mr. W. Worby Beaumont.)

along the sides of the boat, was sufficient to absorb all the power the engine could develop; and if those lengths of narrow section somewhat close to the section of the boat had been considerable, the boat would have stopped altogether, although the engine was of considerable power. There was really a great deal more to be considered than the simple relation between the sections of the waterway and the boat; the backward passage of the water alongside the boat had to be provided for.

Mr. R. **Edmund Froude** wrote to draw attention to a proposition concerning the movement of a vessel along a canal of relatively confined cross section, which, so far as he was aware, was not commonly realised. Reference had been made in the paper (page 164) to the rise of the surface level in a canal at one end of its length, and the fall at the other end, caused by the passage of a succession of vessels, all in one direction; and the same phenomenon, in a less marked form, would of course attend the passage of a single vessel in one direction and none in the other. Now this phenomenon arose inevitably from the fact that the pull of the tow-rope was delivered from the solid ground of the tow-path; for, although this force was immediately satisfied by the resistance of the vessel in the water, it must be ultimately satisfied by a precisely equal reaction brought to bear again upon the solid ground by the water. The only means by which the water could bring such reaction to bear must be either the friction of a general current flowing in the direction of travel of the vessel, or an elevation of surface level at the arrival end of the length of canal above that at the starting end; or partly both. It was evident that both conditions must at one time or another obtain, since there could be no general current in one direction without effecting a difference of surface level at the two ends, nor could such difference of level arise without a current to effect it. The producing agent for the current, and ultimately for the difference of surface level, must consist in the forces of resistance to the motion of the vessel; and the difference of surface level immediately in her front and rear, which was at once the agent of the backward current around her and also one of the elements of the resistance, contributed also to the hydraulic gradient in the canal, which operated to produce the general forward current. But now it was important to notice that the reasoning which thus explained the production of a general current and an ultimate difference of level at the two ends of a canal, by the passage of a vessel or succession of vessels, all in one direction, towed from the bank, forbade the supposition of any such condition arising out of the passage of vessels driven by propellers acting on the water of the canal. For in the latter case no force was delivered from the solid ground, and there could be no reaction upon the ground: action and reaction were alike confined to the water. True the backward current around the vessel must still exist, and so also must the concomitant difference of surface level immediately in her front and rear; the difference would be that here the action of the propeller must restore the surface, somewhere in its own rear, to the same general level as that in front of the vessel. Thus, so far as this reasoning went, the general difference between the two cases would consist in this: that whereas with bank-towed craft the difference of general surface level in front and rear must consist in part of an elevation in front above the normal canal level, with propeller-driven craft it must consist entirely of a subsidence in the immediate rear which was restored again behind the propeller, so that in the latter case the disturbance of the normal surface level would be limited entirely to the water in the immediate neighbourhood of the vessel. There was however an element of general forward current in the canal, which he had not referred to, namely that requisite to cause a reaction upon the ground, equal and opposite to the reaction caused by the friction of the backward current around the vessel; and this element must exist in the case of propeller-driven as well as bank-towed craft.

Mr. Louis Neville wrote that his experience thus far on the Oxford Canal Navigation had been confined to speeds obtained in his iron inspection boat, 56½ feet long by 7 feet beam and displacing 6 tons; its greatest immersed cross section was 7 square feet, which was from 1-12th to 1-17th of the area of the waterway. In the canal

(Mr. Louis Neville.)

the speed of the boat varied from 3½ to 4¼ miles an hour, without any wash that would injure the banks. In the Thames the average speed with and against the stream was 6¼ miles an hour, with the same revolutions of the screw: so that, taking 3⅞ miles an hour as the mean speed in the canal and 6¼ as that in the wider and much deeper water of the river, the loss of efficiency in the canal would appear to be 38 per cent. He hoped to try experiments with hydraulic propulsion, which for canal work he believed would not show in comparison with the screw so much loss of efficiency as had been found to attend it when used in open water at high speeds; and moreover the condition whether the boat was loaded or light would not make so much difference to the hydraulic propeller as it did to the screw.

Mr. J. A. Saner wrote that mechanical propulsion had been in use on the River Weaver Navigation since about 1862, and now the majority of craft were either self-propelled or towed by steamers. The usual course was for one steam flat to tow three ordinary flats, the steamer carrying from 200 to 250 tons, and the others from 180 to 300 tons each. According as the steamers were light or laden or towing other flats, they travelled at any speed up to between 5 and 7 miles an hour, and had to be sufficiently seaworthy to go down the Mersey to Liverpool, and even to make short coasting voyages; all the older vessels were built of timber, while the new were sometimes of timber and sometimes of iron and steel. They were all propelled by screws, which, when the vessels were light, were kept well immersed by the machinery being at the stern end. Their length varied from 80 to 90 feet, with 20 to 21 feet beam; they were built full forward, and with well rounded bilges; the draught ranged up to 10½ feet, which was the navigable depth of the river. The following results had been obtained in some recent trials of three steamers, of which the details had been furnished by the kindness of Mr. J. Rigby, chief engineer to the Salt Union, and of Messrs. Brunner, Mond and Co.; the trials were all made in Vale Royal pond of the River Weaver:—

Name of steamer .	Herald of Peace.	City of London.	Australia.
Length	85 ft. 2 ins.	87 feet	87 feet
Breadth . . .	20 ft. 6 ins.	20 ft. 6 ins.	20 ft. 10 ins.
Draught . . .	8 ft. 6 ins.	8 ft. 9 ins.	8 ft. 10½ ins.
Engines . . .	Non-condensing	Compound Non-condensing	Non-condensing
Cylinders number	Two	Two	Two
Cylinders diameter	12⅜ inches	13 and 20 inches	9½ inches
Cylinders stroke	14 inches	14 inches	12 inches
Revolutions per min.	140 revs.	170 revs.	172 revs.
Power	150 I.H.P.	153 I.H.P.	109 I.H.P.
Load carried . .	171 tons	183 tons	200 tons
Coal consumed .	4¼ cwts. per hour	4 cwts. per hour	3½ cwts. per hour
Propeller blades .	Four, right-hand	Four, left-hand	Four, right-hand
Diameter . . .	6 ft. 6 ins.	5 ft. 5 ins.	5 ft. 1 in.
Pitch	7 ft. 5 ins.	5 ft. 6 ins.	5 ft. 5 ins.
Time per ¼ mile .	160 seconds	162 seconds	160 seconds
Pitch × revs. per minute a	1038·3 feet	935 feet	931·6 feet
Actual distance per minute b	495 feet	488 feet	495 feet
Ratio $b \div a$ . .	47 per cent.	52·19 per cent.	53·13 per cent.

The "Herald of Peace" had run down the Manchester Ship Canal with a loaded barge in 67 minutes, with the same indicated horse-power and revolutions &c. as in the above trials, attaining a speed of 687·1 feet per minute, equivalent to 66 per cent. Independent of any individual instances, the following might be taken as the average trip of the flats on the river under ordinary conditions:—with a steamer carrying 230 tons of cargo and towing two barges of about 100 tons each, the engines showed 157½ indicated horse-power with a boiler pressure of 98 lbs. per square inch. The time taken to travel from below Northwich to Weston Point, a distance of 13 miles, was 3½ hours, including at least 40 minutes spent in the locks; the average speed was therefore about five miles an hour for a vessel carrying and towing 430 tons of cargo. The Weaver locks were capable of accommodating a train as above described all at once, so that delay in locking was reduced to a minimum. At present the section of the river was approximately 45 to 50 feet width at bottom, 100 feet at top, and 10½ feet

(Mr. J. A. Saner.)

navigable depth, though for long lengths it was somewhat deeper; the Manchester Ship Canal was about 120 feet wide at bottom and 26 feet deep. The wash caused by the steamers, especially when light, was considerable, and the banks suffered where not protected; the greatest effect was immediately above and below the surface of the water. The wash caused by the tugs when unladen was far greater than when they were deeply laden. At the different loading berths considerable mischief was also caused below water to stone walls and other protective works by the well-known scouring action of the screw propeller, of which he had frequently made use for dredging with excellent results. When a vessel was being loaded, the man in charge found it much easier to keep the propeller moving slowly, so as to keep the vessel stationary against the current, than to rely on ropes; in fact this was done in order to save the ropes. The consequence was that the stone walls and even piling were gradually undermined; and if the damage was not discovered in time, a slip ensued.

Mr. James Platt, Member of Council, said this interesting paper treated on a subject which had been too much neglected in this country. For the last sixty years little had been done in the improvement of inland navigation. Except on the River Weaver and the Aire and Calder Navigation, and still more recently on the Manchester Ship Canal, little progress had been accomplished. The great railways had monopolised all the enterprise for freight and passenger carriage. Most of the canals were comparatively small; the barges were 70 feet long and only 7 feet wide, except on some of the canals where they were 14 feet wide. They were thus too small for carrying large quantities of freight at a cheap rate, although they still competed with the railways wherever they could be independently employed. It was true that a considerable length of the canals was in the hands of the railway companies, who naturally did not care to develop them; but the railways were not wholly to blame in this matter, for many of the canals had been forced upon the original promoters of the railways. When a railway had been proposed to pass through a district in which there was a canal, it had often occurred that the canal proprietors had threatened a determined opposition if the railway would not take over the navigation; and in some cases the railways had done so, though some of them now wished they had not, because the canals were a great expense, costing more to keep them in order, particularly in the colliery districts, than the revenue derived from them. In the North of France and in Belgium the manufacturers made great use of the canals, and were much helped by the cheap transit provided thereby. It had been found that by increasing the width and depth of the canals, and enlarging the barges, freight could be carried at a much cheaper rate. The enlargement had been made again and again, until now a magnificent system of waterways had been obtained, on which the barges carried freight cheaply. In this country there was a grand railway system, having great facilities for the carriage of goods, but unfortunately not able to carry them cheaply, because the railways themselves had cost such enormous sums. The legislature, the landowners, and the public seemed to put the promoters of railways to great expense, mulcting them in costs in every possible way. This was the reason why they could not carry goods cheaply, and manufacturers had to suffer for it. In America goods were carried a thousand miles for less money than they were carried a hundred miles for in this country; and on the Continent also he believed railway carriage was much cheaper than here. The railways in the United Kingdom paid only a moderate interest on the outlay upon them: so that there appeared to be little prospect of getting the goods rates reduced. It would have been better if canals had been developed more in the past, as they would now have assisted the traffic greatly. Many of the main railways had had to double their lines of way at an enormous expense, in order to cope with the increasing traffic. If some of that money had been spent on canals, perhaps it would not have been necessary to double the lines. Many of the canals had been so neglected that it would be a great undertaking now to put them into anything like working order and bring them up to date. In the paper it had been clearly shown that, if the waterways were properly proportioned to the

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barges, inland navigation would be the cheapest means of carrying heavy traffic. The Associated Chambers of Commerce had been for many years urging on the legislature to pass a measure empowering public bodies to take over the waterways in their respective districts, and to raise money at a low rate of interest, as could readily be done, with the view of developing them and helping the freighters in this way. But up to the present time nothing had been done. It would have been a great advantage to manufacturers if something had been done years ago. Many large manufacturers had indeed removed from the interior of the country to the coast, in order to save the excessive cost of railway carriage; whereas, if the canals and other waterways had been properly developed, this step would not have been necessary. The statistics which the author had taken such great pains in getting together would be of great use, he was sure, to all interested in inland navigation.

Mr. H. R. de Salis thought it would be recognised from a perusal of the paper that the difficulties encountered in the practical adaptation of mechanical propulsion to canal craft were largely distinct from those connected with river and sea-going vessels. For seven years he had himself done little or nothing else but investigate the whole system of inland canal navigation in this country, both from an engineering point of view, and also quite as much in its commercial aspect: collecting information not only on the physical features of the canals, but also as to their trade and the general state of the undertakings as a whole.

Having travelled in his steam inspection launch over nearly all the waterways which communicated with one another, he had found that the speed attained by mechanical propulsion was almost entirely dependent upon the section of the waterway. Alterations in engine-power or in shape of screw seemed to have little effect; a steamboat was simply hobbled by the section of the waterway through which it was travelling. Moreover it was not by any means the actual area of the cross section that made so great a difference; but the greater the depth of water underneath the boat, and the more the sides of the canal approximated to the vertical, the higher was the speed obtained. As an instance, in one of the narrowest canals, namely the Warwick and Birmingham, between Birmingham and Knowle there was an embankment with a walling on both sides; and without any alteration in the steam power or anything else, his boat would shoot ahead along that portion, as if some impediment had been cast off. The same was found to be the case in traversing an aqueduct like the Pontcysyllte near Ruabon in Denbighshire, which was a cast-iron trough with quite straight vertical sides. In such a restricted waterway, only a few inches wider than the boat, it was curious to notice what a good pace could be attained as compared with that in a section much wider but with the usual flat slopes. In 1894 the Grand Union Canal had been purchased by the Grand Junction Canal Company, and had since that time been in process of restoration. Previously it had been not uncommon for a steamer to travel at as low a speed as 1¼ mile an hour through its summit level between Foxton near Market Harborough in Leicestershire and Watford near Welton in Northamptonshire, where the waterway was much choked up. Since the dredgers had been along there, a speed of five miles an hour could now be easily attained by steamers over the same portion. Not that the speed bore a direct proportion to the amended section; for he had no doubt that formerly in many cases the steamer had simply been dragging over the bottom, and ploughing its way through a fair amount of mud and weeds. On large canals, such as the Manchester Ship Canal or the Gloucester and Berkeley, perhaps the conditions under which the traffic was conducted more nearly approached those of open water.

On the Aire and Calder Navigation, where the trains of boats which had formerly been pushed by a tug in the rear were now being towed by a tug in front, the change in this particular had also been accompanied by the abandonment of the wire rope along each side, by which the train used to be steered. The waterway having gradually been so much improved, it had now no doubt been found more handy and economical to do away with the trouble of the long wire ropes and the special steering apparatus, and to leave the tug in front to pull the train into the curved shape for

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going round the bends. The boats were now simply attached each to the stern of the one in front of it, to the number of twelve or fourteen in a train, each boat or box carrying 35 tons of coal; and they were guided without any more steering than was done by the rudder of the tug itself in front of the train. The Aire and Calder was a local navigation, in the sense that none of the other waterways which ran into it could take such large boats as it could itself accommodate. The Bridgewater Canal was also a fine navigation, in a particularly good position to benefit by steam haulage, having a long uninterrupted pound or level between Manchester and Runcorn top lock. The same conditions applied also to the level section of the Shropshire Union Canal from Chester to Ellesmere Port, which afforded great facilities for the towage of boats in trains. There were also small narrow tug-boats in use on the Shropshire Union Canal between Autherley near Wolverhampton and Tyrley top lock close to Market Drayton, a distance of 25 miles with only one intermediate lock at Wheaton Aston. The Shropshire Union Railway and Canal Company being carriers worked the steamers on their own account. A tug started in each direction at six o'clock in the morning, and took in tow the first five of their boats that were ready, thereby saving the use of ten horses during the day. The steam-tugs themselves carried no cargo; they simply towed.

A much more important question was the long-distance traffic by boats which travelled through the country to distant destinations, having to pass through all sorts of canals. No doubt what was wanted more than anything else was some power that would replace the horses ordinarily employed, which were often miserable animals and had a bad time of it. In the west of England a pair of donkeys were usually employed instead of a horse; they travelled still more slowly and were even worse used. Among long-distance routes on which mechanical haulage had been already introduced might be mentioned first the Leeds and Liverpool Canal, of which the portion between Wigan and Liverpool had recently been much improved by putting a side walling on the towing-path side, and deepening the waterway to six feet. There the working of cargo boats by steam tugs could be seen to great advantage. The tugs themselves carried cargo, and were also able to tow two or three butty-boats after them, which made a good paying combination of load. Again, on the canals between London and Birmingham and between London and Leicester there were narrow steam-tugs, nearly all of which were owned by Messrs. Fellows, Morton, and Clayton. Each steamer carried 20 tons, and towed one butty-boat, of which the full load was 30 tons. The pair went all the way up the Grand Junction Canal, passing together through the locks, until they came to the Warwick and Napton Canal, whence to Birmingham they were obliged to lock one behind the other, which caused delay. These steamboats travelled the 140 miles from London to Birmingham, with 160 locks, each towing a loaded butty-boat, with a total consumption for the double journey of from 2·7 to 3 tons of coke, which he thought could not be considered bad work.

In any endeavour to replace horse haulage by mechanical power for the travelling boats on canals, the fact had to be faced that it would not pay to employ a tug solely as a tug, without cargo: it must carry some cargo, or there would not be much profit got out of it. This of course was a great difficulty, cutting down the space available for engine-room, and the weight that could be allowed for machinery; and the best that was possible had to be done within the smallest limits. Moreover there was not much scope for cutting the lines any finer in a steamboat engaged in canal traction; the size of the boat was limited by the dimensions of the locks and by the depth of water in the canal, and the boat was wanted to carry as much as it could for the size of the locks and the draught. Under these conditions the shape of a boat was necessarily very much that of a square-cornered box. If it were cut down to much finer lines, space was lost at once for a few tons, which of course made a hole in the profit on the journey.

Another disadvantage from which steam haulage on canals suffered arose from so many of the through routes by canal to important towns in England being intermixed with river navigation: so that the moment the boats got out of the canal they had to contend with currents and floods. In going from London to Leicester and

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on to Nottingham, for instance, the boats began by going up the Thames to Brentford, whence they would follow the canal to within a few miles of Leicester; there they got into the river Soar, and going north thence to Loughborough and Nottingham they would be in that river and the Trent nearly the whole way. It was evident that a vessel designed for a canal was unhandy in a river. A few years ago he was on one of the London and Birmingham narrow boat-tugs, empty, in the Thames; and at a speed of six or seven miles an hour, instead of cleaving the water, she seemed to push it in front and drag it after her. Sitting for some time on the stern with a box of wooden matches, he kept dropping them overboard and watching the eddies; and in this way he ascertained the fact that, as far as three feet forward of the stern and close to the side of the boat, a match swam alongside in the dead water which she pulled with her.

On canals there was an expense in providing water for the navigation. It was not to be had for nothing, as in rivers where there was a natural flow. The first thing that happened when water began to fall short in a canal was that a system of "waiting turns" had to be adopted: that is, at a flight of locks the ascending boats and the descending boats had to wait for one another, so that the same lock of water might always be used for the double journey. Now in working boats by steam haulage on a canal, they must, as already mentioned, be run in pairs in order to pay; that is, the tug must carry some cargo itself, and must tow another boat after it. It was not worth while to run a tug by itself with what little cargo it might be able to carry. This plan of working in pairs pulled heavily upon the water in narrow canals. A pair of boats would arrive at the lower end of a lock. The tug would lock in first, and go up to the upper level; and then that lock of water had to be drawn off for the butty-boat, before she could also ascend. Then, should there be another pair coming down, the same process took place. It might thus easily occur that three locks of water were drawn out of one pound in quick succession, without any water being put into it in the same time; and in a short pound of a narrow canal this would make a serious difference. It would draw the pound down 3 or 4 or 5 inches, which was enough to upset the progress of the rest of the boats that might be in it, producing the effect which canal boatmen commonly described by saying that the bottom was too near the top.

A further difficulty in the way of mechanical haulage on many canals was found in the excessive number of drawbridges. On the Wilts and Berks Canal from Abingdon to Semington near Trowbridge, which he was sorry to see had just applied for a warrant of abandonment, and on the Oxford end of the Oxford Canal, there were many drawbridges, which had to be opened by a man going on in front. The slopes of the canal banks prohibited getting off and on the boat without a plank. With a horse boat, the driver of the horse was able to perform the work, as he had to be on the tow-path; but with a steamer a man had to go on in front, and must travel as fast as the steamer, or he would not be of any use.

Again, in canals with sharp bends, a horse had great power of assisting the steering round the corners. He pulled obliquely from the path, and a great deal of the steering round the bends was managed by the help of the horse, where the boat rudder by itself would not accomplish it. In this respect therefore a difficulty arose with steamers, which were entirely dependent upon their own rudders.

On the other hand, one of the great advantages of steam propulsion was the fact that the steamers were worked night and day. They had double sets of men on board, one set working while the others were sleeping, which enabled them to proceed to their destination without once stopping. This was much more profitable on the outlay of capital than a horse boat, which had to be tied up during the night.

As to the alleged injurious effect on the banks from a speed of over three miles an hour, a great deal more he thought had been made of this objection than it really merited. Railway-owned canals as a rule were particular about damage from this cause, and laid great stress upon it. But not many years ago a portion of a railway-owned canal in the north passed into independent hands; and steam traffic was at once instituted, where it had previously been prohibited.

(Mr. H. R. de Salis.)

An important point in connection with mechanical haulage on canals was tunnel haulage, which occupied a position peculiar to itself, as it consisted in heavy pulls for short distances. The old method of propulsion through a tunnel was by what was known as "legging." The men lay on their backs, either on projecting wings or in the bows of the boat, and propelled it through the tunnel by pushing their feet against the roof or the side walls. Although this plan was still carried out, an improvement was to be seen at Lappal tunnel on the Dudley Canal, where mechanical propulsion had been set up, though here it was the canal that was propelled, and not the boat. There was a pair of gates at the Halesowen end of the tunnel, which was about 2¼ miles long. The boats were allowed three hours for the passage; and during that time a pumping engine raised water from the bottom pound, and delivered it through the tunnel, thereby producing a perceptible current through the tunnel, which was a great saving to the leggers, as they were able to get through in about two hours; whereas through the Harecastle tunnel on the Grand Trunk Canal in the Potteries, which was only 1¾ mile long, the average time of legging the boats through in dead water was from two and a half to three hours. The next improvement was to put in a horse towing-path through a tunnel, as had been done in the Harecastle new tunnel, which had been driven by Telford alongside Brindley's old tunnel; but the new tunnel with towing path did not seem to have proved such a great success in the matter of speed, in proportion to the outlay. The drawback arose from the fact of the horses having to pull with such a short line that the friction of the boat against the side of the towpath was so great as to prevent it from making much way. The average passage through the tunnel with a loaded boat was still about two hours, so that there was not much saving of time in comparison with legging. There were two good tunnels of modern construction on the Birmingham Canal Navigations, at Netherton and Coseley, each of which had a double tow-path, and a much larger section of the waterway, so that horse boats were able to make good way through them. Tunnel tugs propelled by screws were in use in a great many tunnels throughout England: principally in the Blisworth and Braunston tunnels on the Grand Junction Canal; at Foulridge and Gannow on the Leeds and Liverpool; at West Hill, Shortwood, and Tardebigge, on the Worcester and Birmingham; and at Preston Brook, Barnton, and Saltersford, on the Trent and Mersey or Grand Trunk Canal. The great objection to this mode of haulage was the foul atmosphere which a tug produced in a canal tunnel. Wherever there was water, there was dampness, which caused the smoke to hang; and the greater the traffic through the tunnel, the worse was the air. In the Blisworth tunnel, $1\frac{3}{4}$ mile long, it took a tug about one hour to go through, towing sometimes as many as eighteen or twenty boats, which would give a gross load of 700 or 800 tons. It was necessary to fire up two or three times in the tunnel; and no sooner was the train out of one end than it was time for the tug to go back again with another train. The trips continued from five o'clock in the morning till nine o'clock at night, so that the tunnel had not much chance to clear itself. The tunnel tugs on the Leeds and Liverpool Canal were double-ended boats, with double rudders and propellers, something like the old river steamers on the Thames. On the Worcester and Birmingham Canal the tunnel tugs were about the largest in the country, and consequently towed with greater speed than any of the others. On the North Staffordshire Canal the tunnel tugs had possessed until quite lately a rather peculiar feature, which he thought had been done away with during the last year: namely a pair of horizontal wheels on each side to act as fenders in guiding them through. The reason for their adoption he believed had been that the Saltersford tunnel had a reverse bend in the middle of its length, which had been found awkward to steer round; the tunnel had been made in the last century by driving from both ends simultaneously, and as the two headings did not happen to meet accurately in the middle, they had to be rounded into each other by a double curve. The wheels that acted as fenders had now been done away with, because they had been found greatly to injure the brickwork.

There was one solitary instance of haulage by sunken chain in this country, and that was by the tunnel tug in Islington tunnel on the Regent's Canal.

(Mr. H. R. de Salis.)

There was a great future, he thought there could be no doubt, for any satisfactory plan of mechanical haulage for the ordinary narrow travelling boats or barges on canals. On the whole it appeared to him that the reason why there was not more mechanical haulage on canals was the fact that so many of them were not as yet fitted for it in any way; and that, until waterways had been made or improved so as to be capable of taking boats propelled by mechanical means, there would not be much more seen of it than at present.

Mr. HENRY DAVEY, Member of Council, thought that, although the interesting enigma propounded in the paper, as to the length of the boat being practically immaterial in a restricted channel, seemed to require explanation, the principal reason for it appeared to be simple. The motion of a boat in a restricted channel inevitably raised the level of the water in front of the boat. It had therefore to be moved against a resistance heaped up in front, which would be greater or less according to the restriction of the channel. It was obvious that this head in front was the major resistance, compared with which the skin resistance was insignificantly small: just as, if a loose piston moving in a cylinder were sustaining a column of water in front of it, the mere depth or length of the piston itself would have but little effect in increasing the resistance, because the major resistance was the column of water in front of the piston. Moreover, just as it would matter little to the resistance of the piston whether its face was flat or curved, so it would appear that it would matter little in a restricted channel whether the bow of the boat was flat or curved. But if the same boat was taken into open water, the conditions were altogether altered: the water in front was now displaced at right angles to the moving vessel, and had not to travel backwards through a restricted channel like that between the banks of the canal and the sides of the boat. In the communication received from Mr. Froude (page 208–9) an important difference had been pointed out between pulling the boat from the towing path and pushing it from behind by means of a screw or water-jet. When a canal boat was so propelled from the stern independently of the towing path, the effect upon the water level was altogether altered.

For instead of the difference in level which occurred between the bow and the stern of the boat when hauled by a rope from the towing path, there would now be the reaction of the water behind the screw or jet propeller, which would elevate the water at the stern of the boat. There would thus be an important difference in the resistance met with in pushing the boat by means of a jet propeller or a screw, as compared with that encountered in pulling the boat with a tow rope.

Referring to hydraulic propulsion, when in Glasgow some five-and-twenty years ago he had travelled to and fro on the Clyde in a ferry-boat so propelled, invented by Mr. Ruthven. The water was taken in through a grating in the bottom of the boat, which was flat-bottomed, and was discharged through a nozzle on each side of the boat, the nozzles he believed being partly immersed. The apparent success which attended the working of that ferry-boat induced the Admiralty to have a gunboat constructed on much the same principle, with a few modifications. She was called the *Waterwitch*, and was built by Messrs. Dudgeon. During construction he had several times had the opportunity of seeing the work in progress; and he had been on board when she was completed. The water was taken in through a grating at the bottom to the horizontal centrifugal pump, which was worked by means of a three-cylinder horizontal engine, the cylinders being arranged in plan at angles of 120°. The discharge nozzles were kept just above the water line, and were made to swivel, in order thereby to obtain the great advantage for war purposes that by turning the nozzles either fore or aft the boat could be made to run either astern or ahead; while by turning one nozzle ahead and the other astern, she could be turned round her own centre. There had been some discussion at the time as to whether the greatest efficiency would be obtained from nozzles discharging just above the water line, or from submerged nozzles; and the conclusion arrived at was that the greatest efficiency was to be expected from nozzles discharging just above the water line, quite clear of the water line and not immersed in any way whatever. For the boat illustrated in Plate 40, having the nozzles wholly immersed, and rather deeply immersed, an astonishing

(Mr. Henry Davey.)

efficiency had been claimed, which he thought there might be some hesitation in accepting without more conclusive evidence. Here the power of the engine was spent in driving a centrifugal pump; and however efficient such a pump might be made, in ordinary practice he thought the efficiency of a pump arranged in a boat as shown in the drawing would hardly exceed 70 per cent. What then was to be the efficiency of the jet itself? Could the reaction of the jet itself give a greater efficiency than the reaction of a screw? In default of any experience of his own he should imagine it would be much less. Assuming the pump to give an efficiency of 70 per cent. and the jet to give also an efficiency of as much as 70 per cent., the total efficiency would be no more than 49 per cent.; and he could not see how it was possible to obtain a combined efficiency of pump and jet together which should be greater than the efficiency of a screw.

On the plan which had been mentioned (page 220) of conveying boats through a canal tunnel by pumping the water itself and carrying the boats through in the current so created, instead of hauling or driving them through the water, it would be noticed that the level of the water surrounding the boat remained the same in relation to the boat, and practically the latter was transported in quiet water. Here the work done was the friction of the water in the channel; and therefore in this instance, the smaller the channel, the less was the resistance for a given speed of water, because the less was the wetted surface. In greatly restricted channels this seemed indeed a highly estimable method of propulsion, because the boats could be crowded as close as possible after one another, until the whole channel might be full of them. But what became of the water pumped in at one end of the channel? Was it to be discharged at the other end? If so, and if at the lower end the water had to be pumped up from a level below the surface of the channel, the work done in raising the water had to be added to the work of putting the water in motion. The most economical method of carrying out the plan would be to do away with the necessity of lifting the water at all, and to expend the power simply in giving it motion. To do this it would be necessary to divide the tunnel into two channels by a brattice, so that there could be boats travelling along one side of the brattice in one direction and along the other side in the contrary direction; and at the ends of the tunnel it would be only necessary to have a propeller, which would put the water in motion and circulate it through the two channels.

Professor Alfred Chatterton, referring to the resistance of a boat being independent of its length, considered the explanation offered by Mr. Davey (page 222) seemed quite intelligible in regard to boats travelling in a restricted waterway. But from pages 151 and 155 of the paper he gathered that the experiments in Table 7 had been made in the River Seine, where the waterway was practically not restricted, and had also been confirmed in the Bourgogne Canal afterwards. It therefore appeared that the heaping up of a head of water in front of the boat in a canal would not suffice to explain the fact that in canal boats, as distinguished from other boats, the skin friction seemed to have no appreciable effect upon the work required for propelling the boat along. In India, where he had had some experience in connection with boat navigation on canals, the circumstances were as different as they possibly could be from anything prevailing in this country. In nearly all the canals in India, irrigation was combined with navigation; and the consequence was that the navigation was more like that of a river than of a canal. There was practically no mechanical means for propelling the boats along, and the whole of the hauling was done by gangs of coolies, who towed the boats up and down stream. From the fact that the canals had to be used for irrigation at different seasons in the year, the quantity of water in them varied greatly at different periods; and it was therefore easy to make comparatively rough experiments as to the effect of different depths of water upon the resistance offered to the traction of boats. The observations he had made upon this subject he thought confirmed generally the experiments recorded in the paper, and the remarks already made in the discussion.

Regarding the suggestion that electricity might be applied for propelling canal boats, probably there were no canals in the world better situated for this purpose than some of the big delta canals in

(Professor Alfred Chatterton.)

India, where the quantity of water flowing down was so large that there were some locks with 400 or 500 horse-power available, which might be converted into electrical energy and used for towing. At present indeed it was only on one or two of these canals that the traffic could possibly be large enough to justify the adoption of this plan, if it were feasible. But the difficulty that occurred with all electrical methods was the heavy initial expenditure required. In one instance, not connected with the towing of boats, he had had to make proposals for pumping a large quantity of water; and he had found that, although the power from one of the canal locks would be ample, it was much cheaper to put up a steam engine and generate the power by burning coal under boilers, than to utilize the water-power absolutely free of cost, which was available within a few miles of the site of the pumping station. For this reason it seemed probable that it would be a long time before it would be practicable to introduce electrical methods of propelling boats along the large waterways in India. The only alternative therefore was to adopt some method of moving boats by steam power, either by screws or by jet propellers. In continuation of Mr. Davey's remarks on the efficiency of the jet propeller (page 223–4), if B represented the velocity at which the boat was moving, and J the velocity with which the jet issued, the efficiency* of the jet propeller would be equal to $\frac{2B}{J+B}$. Therefore if the velocity of the issuing jet was twice the velocity at which the boat was moving, the maximum theoretical efficiency of the jet propeller under these circumstances would be two-thirds. As a matter of fact, with the ordinary arrangements of jet propellers hitherto tried, the efficiency was considerably less than this possible maximum. If the velocity of the jet was equal to the velocity of the boat, the efficiency became unity; but then the capacity of the propeller for doing work became practically nothing at all. The jet propeller was much like an electric battery, which had an efficiency of unity when the current was flowing through an exceedingly great external resistance, but it would then be doing an exceedingly small amount of work; and as the external resistance diminished, so the current would increase, and with it the amount of work done, but at the same time the efficiency of the battery would decrease, owing to its own internal resistance. So with the jet propeller, the greater the difference between the speed of the jet and the speed of the boat, the greater was the want of efficiency in that method of propulsion. Especially therefore on canals, where the speed of the boat must necessarily be low, the velocity of the jet would be high in comparison with that of the boat, and the efficiency would be low. No doubt the particular form of nozzle employed in the experiments plotted in Plate 44 had added somewhat to the efficiency of the jet. The simple reason seemed to be that it was shaped to the form of the *vena contracta*, and thereby protected the jet from disturbing eddies, which otherwise broke up the issuing stream of water and prevented it from being properly utilised.

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* See "Hydro-mechanics" in Encyclopædia Britannica, ninth edition, vol. xii, page 515.

Mr. Robinson agreed with Mr. Froude (page 208) in regard to the difference in the effect produced by the passage of bank-towed and propeller-driven craft in a canal, so far as concerned the general level of the water. But in the immediate neighbourhood of the boat there was in both cases the same head of water in front, while with the propeller there was in addition the drop in the level astern, due to the action of the propeller in driving the water backwards away from the stern. Mr. Neville's experience showed a loss of about 38 per cent. (page 210) in going from the River Thames into the Oxford Canal, in which the cross section of the waterway was from 12 to 17 times that of the boat. This confirmed the tenour of the paper, though not the actual figures given therein.

The wearing of the canal banks had been considered in the paper in relation to the surface waves, which necessitated the limitation of the speed to three miles an hour for propeller-driven craft in a restricted channel. The destructive surface action upon the banks at a higher speed was distinct from the scour alluded to both by Sir Leader Williams and by Mr. Saner.

(Mr. Robinson.)

In arranging any plan of mechanical propulsion for canals, the importance had been pointed out by Sir Leader Williams (page 190) of such an amount of elasticity in the system adopted as would admit the traffic of other boats driven on other plans. This was an aim which must be kept in view, because if it was neglected there would be a difficulty in passing from one canal to another.

In regard to the question of cost, referred to by Mr. Macfarlane Gray (page 206), Mr. Barcroft had kindly furnished some recent figures which would be of interest. From one of his boats running on the North of Ireland canals, for which the original outlay had been £560, the dividend paid this year had been 17 per cent. This he thought was a remarkably good financial result, considering that the displacement of the boat was only 106 tons, of which the machinery occupied only 3½ per cent. But as to details of cost, it was extremely difficult to institute any comparison between various canals, more particularly when dealing with the canals of two different countries; and he was sorry that in consequence he had not been able in the paper to reduce all the costs to the same basis.

Had Swedish and German results (page 199) been included in the paper, in addition to those obtained in France, he feared it would have been far too voluminous.

With Mr. Walker's conclusion (page 204), that the depth of the waterway did not make so much difference in the resistance as its width did, he could not agree, because it was diametrically opposite to the experience gained almost universally: namely that, when working with a propeller in a narrow channel, or with such limited draught that the propeller was close to the bottom of the canal, it was found that the depth had more influence than the breadth upon the resistance. This he believed had been proved over and over again.

By way of verifying Mr. Macfarlane Gray's suggestion (page 206) that the ratio of sections, instead of being taken as given in the paper, ought to have 1 subtracted from it, on account of the channel being diminished by the immersed midship section of the boat, he had worked out afresh the curves in Plate 34 for the ratio so amended, and had found that, as anticipated by Professor Smith (page 206), the difference was merely algebraical. The new lines were absolutely parallel to those already plotted; and, though slightly lower, were so close to them that the interval was only just visible.

How the control of canals by railways had been brought about had been explained by Mr. Platt (page 212). However acquired, it had none the less acted most disadvantageously upon the development of mechanical propulsion in canals; and he thought the main reason why the larger canals in France were so much ahead in this respect was that they were not hindered in the same way. The development of canals in this country would no doubt be a most important advantage to the manufacturers.

For many years Mr. de Salis had been investigating the actual daily working of canals; and having travelled with him on some of the canals in his steam launch, he had himself noticed the considerable gain in speed on passing through an improved section where there was greater depth of water under the screw propeller.

The plan of generating a current of water through a tunnel (page 220) was an ingenious way of getting over the difficulty of tunnel navigation. He was informed by Mr. de Salis that, at the end of the tunnel where the pumping engine was situated, were a pair of stop gates, from the lower or outer side of which the water was drawn and delivered to the upper or inner side; and flowing through the tunnel it accumulated in the pound beyond, which acted as a reservoir and was some two miles long. When the direction of the traffic through the tunnel was reversed, this accumulated water was allowed to flow back again, until the level on both sides of the stop gates was again the same.

The shape of the boat had been dealt with in page 165–6, where the results were given of M. de Mas' experiments on the *Péniche* and the *Toue*, these two boats having a difference in displacement of about 100 tons (Table 4). It would be observed that, while the loss of carrying capacity in the *Toue*, consequent upon her slightly rounder bow, was only 6 tons out of 242, it was attended with an important reduction in the resistance to traction. Moreover, while the difference in displacement of the two boats was 100 tons, it was only when they were both fully loaded that this small loss of 6 tons in the carrying

(Mr. Robinson.)

capacity of the smaller boat came into the account; in order that it might be appreciated at all, the boat must be fully loaded.

As to the resistance to traction being independent of the length of the boat, the experiments in Table 7 had been repeated under varying conditions, and their practical teaching was that the length did not make much difference, if any. This conclusion was also corroborated by the observation that on the Aire and Calder Navigation, as mentioned by Mr. Wicksteed (page 202), the gaps between the boats in a train seemed to make but little difference in the tractive power required. No doubt an explanation of the resistance to traction being independent of the length of the boats within the limits of the experiment was to be found in the elements composing the resistance to traction. These might be taken to be:—firstly, the resistance on the bow, which would here be identical for the three boats; secondly, skin friction; thirdly, the negative pressure on the stern. It was the simultaneous variation of these last two quantities which must account for the phenomenon under discussion. The heaping up of the water in front of the bow, to which attention had been drawn by Mr. Davey (page 222), would of course be the same for the two extreme examples in Table 7, the coefficient of fineness for all three boats being about 99 per cent.

In India, as pointed out by Professor Chatterton (pages 225–6), there were no doubt places where there was a large amount of water flowing down the canals, and where perhaps, if the traffic was large enough, electric traction might be adopted. An instance had been given in the paper (page 177) of the saving that had been brought about by that plan; but it could be only in places where the traffic would warrant the necessary outlay. Electric haulage on canals was like electric traction upon tramways; it could not be made to pay in ordinary tramway work unless the traffic was sufficiently continuous.

As to the efficiency of the nozzles devised by Mr. Capell for hydraulic propulsion, he thought the explanation given by him (page 200) and confirmed by Professor Chatterton (page 227) was the right one: namely that the internal shape of the nozzle was that of the *vena contracta*, and therefore the jet discharged was not disturbed by eddies of the water outside.

The PRESIDENT was sure the Members would all agree that Mr. Robinson deserved their warmest thanks for his valuable contribution to the important subject of inland navigation, upon which his paper had also elicited so interesting a discussion.

Mr. LIONEL B. WELLS wrote that in 1885 he had made some experiments on canal-boat propulsion, in a canal about 90 feet wide at the surface and from 11 to 12 feet deep, having a sectional area of about 700 square feet. The trial was made with a steam tug 76 feet long and 12 feet 8 inches beam, having a draught amidships of 5 feet 3 inches, and an immersed midship section of about 60 square feet. The speed attained was about 7½ miles an hour in the canal, and on a broader expanse or lake it rose to about 10¼ miles, the actual increase being 34½ per cent. Over the same course was tried a steam launch 79 feet long and 7 feet 9 inches beam, having an immersed section of about 30 square feet. In the canal she made 7½ miles an hour, the same as the tug, and on the lake about 8¼ miles, the actual increase being 9·9 per cent.

The experiments made by M. de Mas appeared to him not to agree with one another. If skin friction went for nothing in a canal, as would seem to be the case from the statement in pages 154–5 that the resistance to traction was entirely independent of the length of the boat, how came it that the resistance varied considerably, as stated in page 154, according as the wetted surface of the boat was more or less smooth? If the advantage of a smoother surface was considerable, it must he thought have been discovered long ago in practice; and instead of nearly all canal boats continuing to be built of wood, metal would have come into general use. Boatmen did not fail to report sluggish boats, and to comment on their form; but although he had formerly had both wood and iron boats in use, he had never heard a remark on any difference in traction arising from difference in the material.

On the Aire and Calder Navigation the mode of propulsion had been changed from the stern to the bow shortly after the introduction of the plan of carrying coal in compartments.

Mr. THOMAS CLAYTON wrote that what was chiefly required for improving canal-boat propulsion was that the navigations themselves should be improved. So far as regarded the existing navigations with which Messrs. Fellows, Morton, and Clayton were concerned—namely the Grand Junction and Warwick Canals, the Oxford Canal, and the Union Canals to Leicester and Nottingham—he considered his firm had obtained the best results with steam craft which it was practicable to obtain at present. During the next few years they hoped to see considerable improvements in the navigations; and then improved craft would speedily follow. As to the damage alleged to be caused to canal banks, their own experience was that with the craft they employed it was impossible to damage the banks, because in the existing condition of the canals the boats could not attain sufficient speed to do damage; and moreover in the construction of their screw propellers this matter had received consideration.

Mr. ROBINSON wrote that the statement in page 154–5 of the paper, referred to by Mr. Wells (page 231), dealt with the friction upon surfaces differing in size but of the same kind, and showed that beyond a certain point the increase of surface had not the same influence on the total resistance to traction as before reaching that point; whereas the earlier statement in page 154 dealt with the comparison of surfaces differing from one another in roughness, and not in area, and consequently could not be held in any way to contradict or disagree with the subsequent statement in page 155. These results had been put forward by M. de Mas as applying only within the limits of the experiments made by him; consequently there must not be assigned to them too general a character.

MEMOIRS.

Robert Fogg, son of Mr. James Fogg, was born at Bolton, Lancashire, on 9th September 1822, and was educated at Bolton Grammar School. After serving a pupilage of seven years under Mr. Isherwood, mechanical engineer, of Leigh, near Manchester, he entered the service of the Egyptian government, as engineer in charge of the construction of reservoirs, public buildings, &c. Returning to England, he was engaged from 1849 to 1851 in the design and erection of cotton factories near Preston. From 1852 to 1855 he was in Russia, employed by Messrs. Baird on the erection of a bridge across the River Neva, and by the Volga Steam Navigation Co. as an assistant engineer. In 1855 he returned home, and for two years had the management of the drawing office at the Regent's Canal Ironworks for Mr. Henry Grissell. In 1857 he was appointed manager of the London business of Messrs. Cochrane, Grove, and Co., of Middlesbrough, and of Messrs. Cochrane and Co., of Dudley, which post he retained until his retirement in July 1893. Since 1868 he was also in practice as a consulting engineer, and was for some years employed in preparing designs for bridges, steamers, barges, &c., for the Egyptian government, and for other similar works in this country. In 1890 he received the Ottoman order of the Osmanieh from the Khedive of Egypt. From 1893 he lived in comparative retirement at West Norwood, London, where his death occurred on 13th August 1897, in his seventy-fifth year. He became a Member of this Institution in 1859; and was also a Member of the Institution of Civil Engineers.

Nathaniel Grew was born in Norwich on 6th October 1829. After serving a pupilage with Messrs. W. Bridges Adams and Co., Fairfield Engineering Works, London, from 1846 to 1849, he was employed until 1851 on the South Eastern Railway in London and at Ashford. From 1851 to 1853 he was engaged upon the survey and setting out of part of the Madrid and Valencia Railway on the section from Albacete to Almansa, under the Marquis Salamanca and Mr. W. Greene. From 1854 to 1859 he was chief assistant to Sir William Siemens in connection with his improvements in engines, furnaces, and iron and steel manufacture. In 1860 he commenced business on his own account as a civil engineer in London, and was consulting engineer to several large mercantile firms, having charge of their engineering work. For some years he was connected with railway work in the Argentine, Central America, Peru, and Brazil, advising on the supply of material to lines in those countries. His last important work was the construction of the produce market at Bahia Blanca for the Bahia Blanca and North Western Railway. He designed a locomotive for running on ice, which was reported to have worked successfully in Russia on the River Neva during the winter of 1861, conveying passengers and goods between St. Petersburg and Cronstadt. A model of it, shown in the Exhibition of 1862, is now in the South Kensington Museum. His death took place at his residence at Lee, London, on 11th July 1897, in his sixty-eighth year. He became a Member of this Institution in 1874.

Francis Gassiot Houghton was born in Kennington, London, in February 1858. In 1875 he was engaged on general engineering work at the Crossness Main Drainage Works of the Metropolitan Board of Works, now the London County Council, under the late Sir Joseph W. Bazalgette, C.B.; he also supervised as assistant superintendent the construction, testing, and erection of large engines, rotary and centrifugal pumps, boilers, and electric-light installation. In 1884–5 he designed machinery for the manufacture of manganate of soda, which was largely used for the disinfection of sewage, and thereby reduced the price from about £20 to less than £10 per ton. From 1888 to 1893 he frequently acted as superintendent at these works. In 1893 he left the employment of the London County Council, and commenced business on his own account in Westminster as consulting engineer. At the end of 1896 he went to Johannesburg, but in consequence of the unsettled state of affairs he returned in March 1897, and resumed his former business. His death occurred accidentally by being washed off a yacht near Southend at the mouth of the Thames, on 4th September 1897, at the age of thirty-nine. He became a Member of this Institution in 1892.

THOMAS FREDERICK IRWIN was born in Birmingham on 10th May 1848. He commenced his apprenticeship in January 1863 at the Britannia Iron Works, Sunderland, and at the end of 1866 went into the service of Messrs. Thompson and Boyd, Newcastle-on-Tyne, where he completed his apprenticeship, and remained some years as journeyman. On leaving them he went to the works of Messrs. Samuel Tyzack and Co., thence to Messrs. William Pile and Co., shipbuilders, Sunderland, to the North Eastern Marine Engine Works, Sunderland, and then to a firm in Stockton-on-Tees. He next went to sea for a time as a sea-going engineer, and then from 1870 to 1877 was draughtsman and manager to the Wallsend Slipway Co. From 1877 to 1883 he was superintendent engineer to the Inman Steamship Co. of Liverpool, where he superintended the building of the "City of Rome" and other steamers. In 1883 he commenced business in Liverpool as consulting engineer and naval architect, and in 1889 entered into partnership in the firm of Irwin, Atkinson, and Young. Having been for some time in indifferent health, he died at Gilsland, near Carlisle, on 11th June 1897, at the age of forty-nine. He became a Member of this Institution in 1894.

JOHN EDGAR LOWE was born in Derby on 20th May 1839. He was educated at Derby Grammar School, and afterwards in France. In 1855 he commenced an apprenticeship with Messrs. Handyside and Co., Derby; and went to London in 1861 to become engineer to the firm of Messrs. William Bird and Co. In 1879 he entered into partnership with Mr. Bolling as Messrs. Bolling and Lowe, engineers and contractors, and succeeded to the business of Messrs. William Bird and Co. Having been in feeble health for some time, he died in London on 17th October 1897, at the age of fifty-eight. He became a Member of this Institution in 1873.

JOHN RAMSBOTTOM was born at Todmorden on 11th September 1814, his father being a small cotton-spinner, who owned the first steam-driven mill in the valley. Here his education was that of a remote village, where after a short time spent in a dame's school he went to four schoolmasters in succession, then to a Baptist minister, and finally to a colleague of the latter, who taught him as far as simple equations, leaving him to show afterwards, like many other self-educated men, that the true university was his own mind and power of thought. His father having given him a 6-inch lathe, rigged up in the warehouse, he constructed various models of steam-engines, including a beam engine with condenser, an oscillating engine, Hero's reaction engine, a water-raising engine, and a small locomotive engine to run upon a table or upon the floor. Later he made a stationary "table" engine, with upright 5-inch cylinder and 18-inch stroke, and an overhead crosshead with side-rods down to a crank shaft underneath the table; it was worked with steam of the then high pressure of 50 lbs. per square inch, of which the villagers took notice that it looked rather blue as it escaped from the safety valve. For a friend who was a confectioner he made an engine with 4-inch cylinder and 12-inch stroke. Of more importance was his reconstruction and erection of the engine in his father's mill, including a larger cylinder of 18 inches diameter and 4 feet stroke, a new beam, connecting-rod, air-pump, and condenser, the last two being purchased from Messrs. Peel, Williams, and Peel, Soho Iron Works, Manchester; he also designed and fitted up new side pipes with slide-valves, and a new parallel-motion. He carried out the lighting of the mill with coal gas, which at that time was the new illuminant. He also schemed, made, and successfully worked an automatic machine for the manufacture of cut nails. Probably the most notable invention of those first twenty-five years of his life, spent at Todmorden, was the weft fork or weft stopper, now universally adopted, without which it would be impossible to work looms at a high speed. He was active and enthusiastic in the interests of the first Mechanics' Institution at Todmorden, possessing quick literary perception and an appreciation of whatever was graceful and intellectual. About 1839 he went to Manchester, and entered the service of Messrs. Sharp, Roberts and Co., who already enjoyed a high reputation as makers of locomotive engines and of cotton-spinning machinery. Thanks to the practical experience he had acquired at home, he at once obtained employment and pay, without preliminary apprenticeship; and here he first gained practical knowledge of the design and construction of locomotives. His enthusiasm, industry, and ability speedily attracted the attention of Mr. Charles F. Beyer, the head of the locomotive department of the works, who had himself worked his way up to that position by the energetic exercise of the same qualities. After three years' service he was appointed in 1842 on Mr. Beyer's recommendation to be locomotive superintendent of the Manchester and Birmingham Railway; the locomotive sheds were at Longsight, where he had under his charge a number of engines constructed by Sharp, Roberts and Co., and by Robert Stephenson and Co. In 1846 several lines previously independent were united to form what was thenceforth known as the London and North Western Railway, on which his appointment became that of district superintendent of the north eastern division. On 1st August 1857 he was promoted to take charge as locomotive superintendent of the northern division at Crewe Works, in succession to Mr. Francis Trevithick; this division then comprised all lines north of Rugby, including the Trent Valley from Rugby to Stafford, as well as the old route northwards viâ Coventry, Birmingham, and Wolverhampton. In 1858 he turned out a number of new goods engines, having inside frames and inside bearings only, with inside cylinders 17 inches diameter and 24 inches stroke, and six coupled wheels of 5 feet diameter; many of these are still at work after nearly forty years' service, and they remain the standard. In November 1859 he completed and placed in daily traffic the first of his class of express engines, which he named the "Problem," afterwards changing the designation of the class to the "Lady of the Lake." These engines he continued to build till July 1865: they had cylinders 16 inches diameter and 24 inches stroke, and driving wheels 7 ft. 7½ ins. diameter; the engine weighed 27 tons in working order, and the tender 17½ tons, making 44½ tons total. The "Problem" was the first engine in this country to be fitted with the Giffard injector. Altogether sixty of these single engines were built, all of which are still at work and appear to have many more years' life yet before them. Previously to 1863 all passenger engines had been single, while all coupled engines had been reserved for goods traffic; but in that year the weight of some of the fast main-line trains led him to take the novel step of introducing express passenger engines having four wheels coupled. Several of these were built, in addition to thirty small shunting engines on only four wheels, which were coupled.

In 1862 it was decided to concentrate the whole of the locomotive work at Crewe, and to use the former locomotive shops at Wolverton for carriage building. Being confirmed in the control of the Crewe Works, he was now able to give full scope to his mechanical ability and ingenuity. Paying the greatest attention to facilities for the economical manufacture and maintenance of engines, he reduced the number of classes to the utmost, and their parts to as great a degree of uniformity as possible, thereby enabling repairs to be speedily executed. The system of working to standard gauges was also carried out, whereby not only were new parts made accurately to standard dimensions, but also a series of graduated sizes was adopted for renewing worn details. Special tools were largely introduced throughout the works; and particular attention was paid to the convenient handling of the work, and to its transference from one department to another. The improvements he effected for the latter purposes included the extensive introduction of traversing cranes driven by high-speed cotton ropes, and the narrow railway of 18 inches gauge, which ramifies everywhere through the premises, and performs such useful work. Under his direction were introduced at Crewe the Bessemer and open-hearth processes of steel manufacture; and in this connection he originated several notable deviations from what had till then been the ordinary practice: namely, a powerful cogging mill, made of segments of rolls of large diameter, which proved highly effectual for putting the first heavy work into the Bessemer ingots; a horizontal duplex steam-hammer, having two hammer-blocks running horizontally upon rails and propelled against each other by a horizontal steam cylinder behind each; and a plan of reversing a train of rolls by reversing the engine itself, which is comparatively quick-running, instead of by the cumbersome and destructive clutch-arrangement then in vogue in connection with a slow continuously running engine having a heavy fly-wheel. The reversing of the engine was effected by steam or hydraulic power, readily controlled by a lad; and the draft of the rolls themselves was similarly controlled, the adjusting screws in the housings being geared together so as to ensure absolute parallelism. Among the most important of his numerous efforts to improve the construction and working of locomotives were the steps he early took for adopting the use of coal instead of coke, his arrangement of air admission for the prevention of smoke being entirely effective; the displacement lubricator, which was the forerunner of "sight-feed" lubricators in general; light piston with simple packing-rings exerting equal pressure all round; an improved form of the double-beat regulator; duplex safety-valves, which could not be tampered with; telescopic boiler; solid coupling-rod ends; weldless steel tires forged and rolled from conical ingots; portable appliances for re-boring cylinders and planing up valve-faces of locomotives *in situ*, which he schemed and introduced in the early days at Longsight; and the plan by which he is perhaps best known to the public, for enabling locomotives while running to pick up water from a trough laid on the permanent way.

He was one of the original Members who joined in constituting this Institution at its establishment on 27th January 1847; and was for seven years a Member of Council, for thirteen years a Vice-President, and President in 1870 and 1871. During that period he contributed no less than thirteen papers upon his inventions. As early as 1849 he gave a description of an improved locomotive boiler, in which he sought to obtain by means of a separate steam-chamber a larger flue area and larger heating surface, with less relative bulk and weight, and with great simplicity of construction. In 1853 he described an improved coking crane for supplying locomotive engines; in 1854 the light and simple piston for steam engines, and in 1855 the construction of the simple packing rings so shaped as to exert equal pressure all round the cylinder. Then followed in 1856 the duplex safety-valves which cannot be tampered with; and in 1857 a description of Mr. William Routledge's safety escape-pipe for steam boilers. In January 1861 he described the method of supplying water to locomotive tenders whilst running, the first water trough having recently been laid on the Chester and Holyhead line near Conway, where it had successfully stood the test of the severe winter 1860–61. The general adoption of the plan on all main lines is the best testimony to its value; without it the long runs now made by express trains would be impossible. In 1864 he described the traversing cranes at Crewe; in 1866 the reversing rolling mill; and in the same year the manufacture of weldless steel tires, by forging from a conical ingot, giving a plain bevelled edge to the bloom by hammering on a beck iron, and finally rolling in the circular rolling mill invented by Mr. Peter Rothwell Jackson. When in March 1870 the endless-rope haulage of trains through the Edgehill passenger tunnel at Liverpool was abandoned in favour of ordinary locomotive traction, he devised and successfully carried out the mechanical ventilation of the tunnel by means of an exhausting fan, of which he gave a description in two papers during his presidency in 1871.

Failing health compelling him to relinquish such active work and such weighty responsibilities as he had borne for fourteen years at Crewe, he retired in September 1871 from his position there, after having been nearly thirty years in the service of the railway. While at Crewe he took an active interest in the local Mechanics' Institution, of which he was President; and after leaving he founded in 1873 at the Owens College, Manchester, the Ramsbottom scholarship of £40 per annum, tenable for two years, to be competed for by young men employed in the locomotive department of the London and North Western Railway. In 1883, having in the interval happily succeeded in recruiting his health, he became connected with the Lancashire and Yorkshire Railway, and acted as their consulting engineer for the design and construction of their works at Horwich; and in 1885 he was elected a director of the railway, which position he only recently resigned. He was also a director of Messrs. Beyer, Peacock and Co.'s works. He was a governor of the Owens College, and a generous contributor to the fund for building a medical school in connection therewith. He was also an old Member of the Manchester Literary and Philosophical Society; and was elected a Member of the Institution of Civil Engineers in 1866. In 1888 the honorary degree of "Master in Engineering" was conferred upon him by the University of Dublin as a Past-President of this Institution, upon the occasion of the Summer Meeting of the Institution being held for the second time in the capital of Ireland; this is the highest engineering degree, and had been conferred *honoris causâ* in only six previous instances. His last appearance among the Members of the Institution was as a guest at the dinner at the Manchester Meeting on 1st August 1894, when he proposed the toast of "The Owens College." His death took place at his residence, Fernhill, Alderley Edge, on 20th May 1897, in his eighty-third year, after some months of illness patiently borne.

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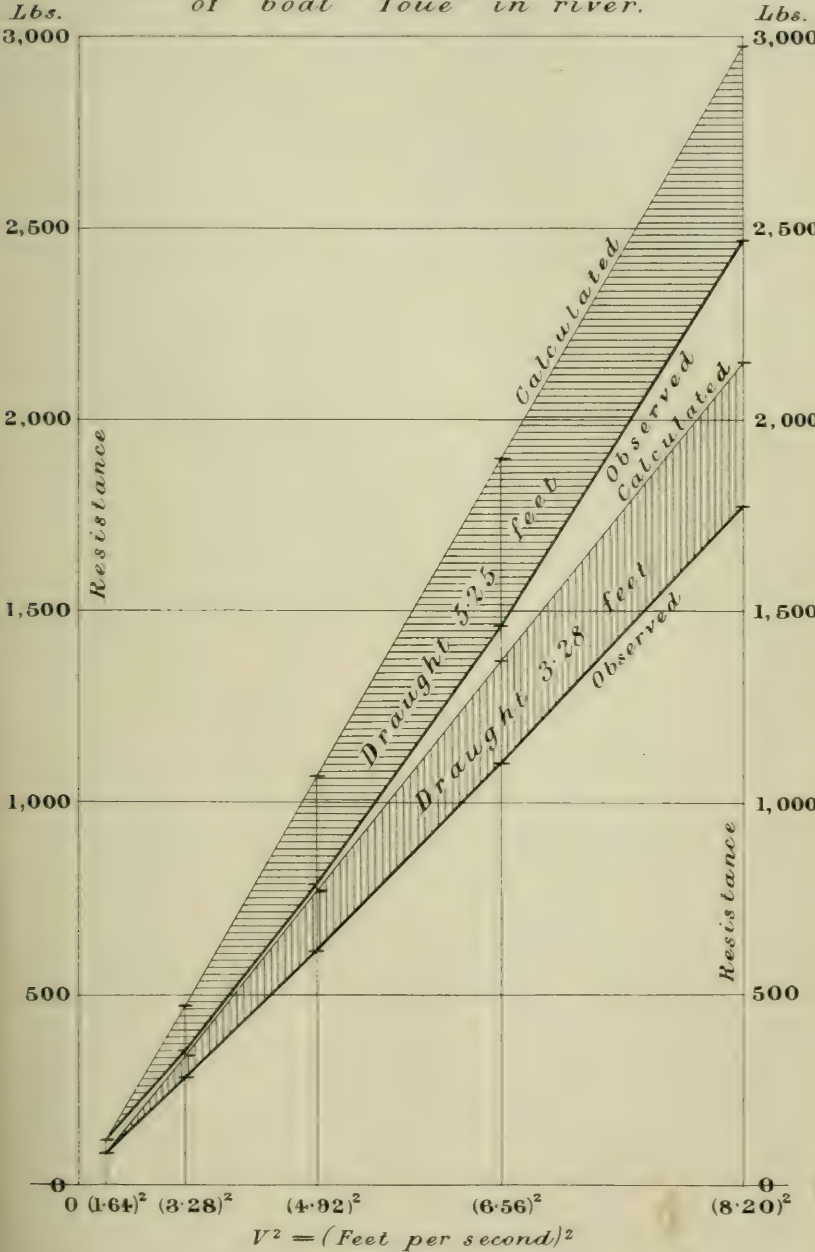
CANAL-BOAT PROPULSION. *Plate 28.*

Table 2.

Observed and Calculated Resistance to traction of boat "Toue" in river.



Mechanical Engineers 1897.

Table 3 and Table 4.

Resistance of four Boats to traction in river; also Immersed Midship Section.

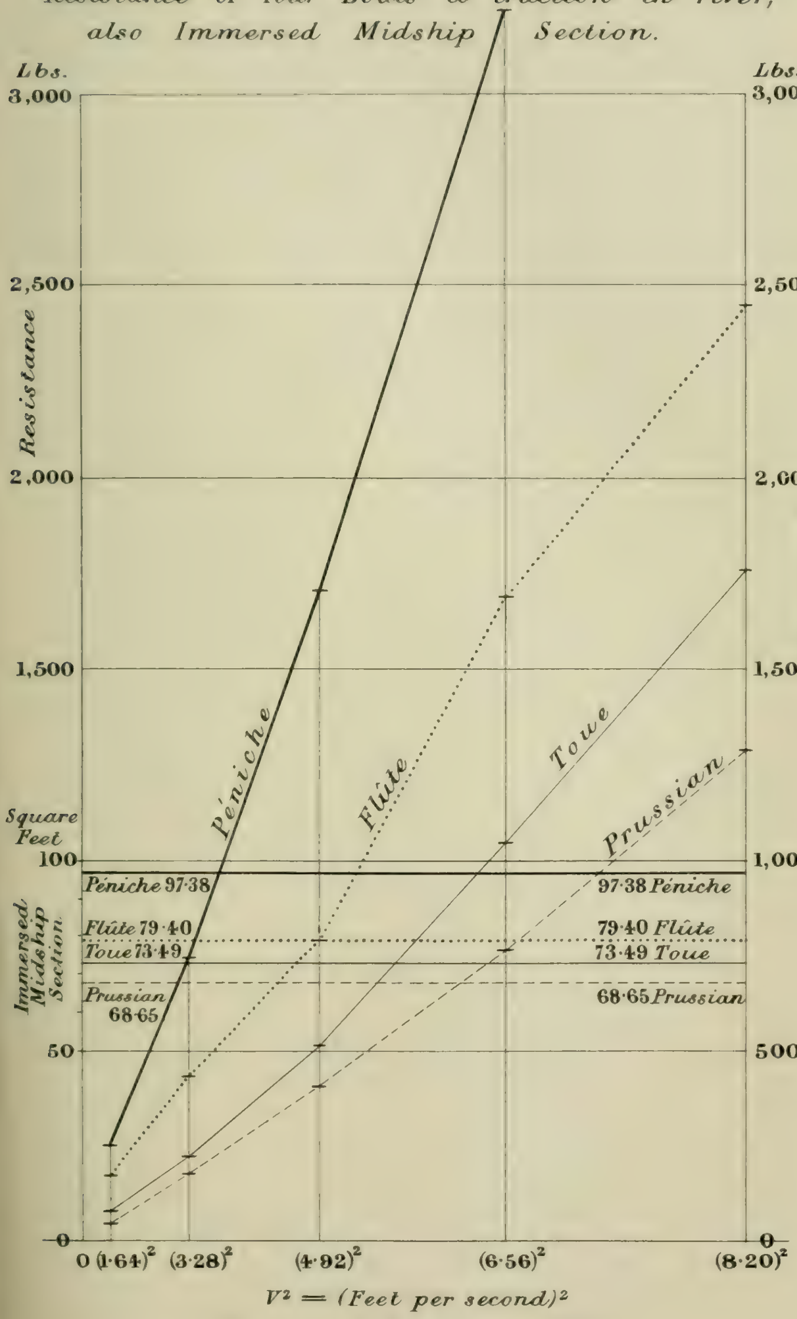
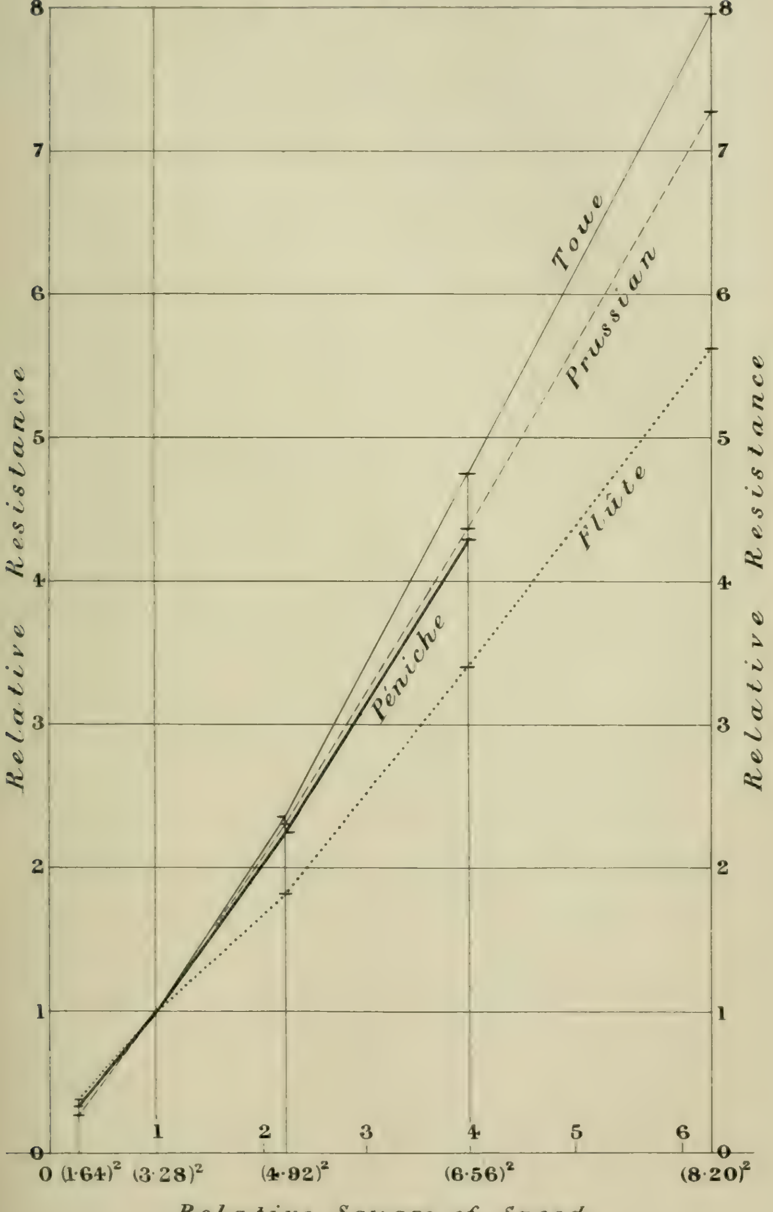


Table 5.

Relative Resistance of four Boats to traction at different Speeds in river.

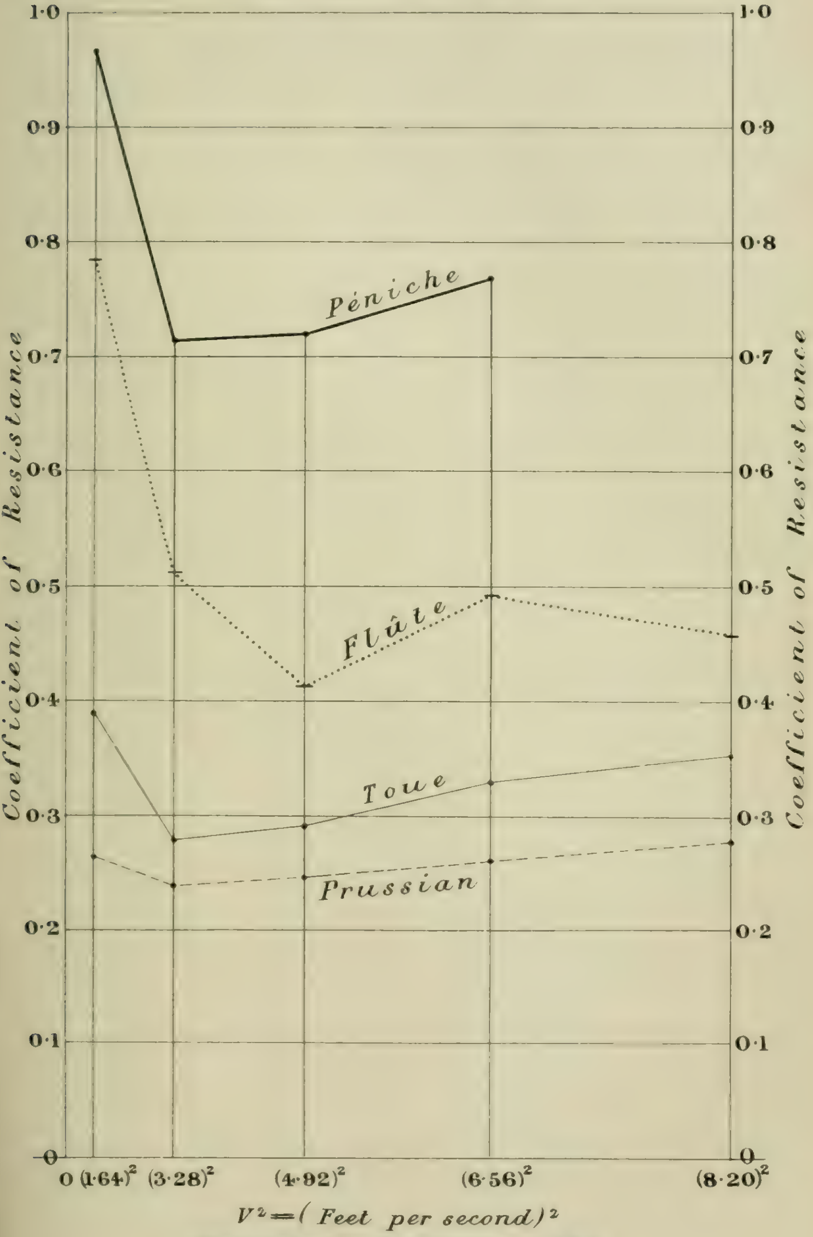


Mechanical Engineers 1897.

CANAL-BOAT PROPULSION. *Plate 31.*

Table 6.

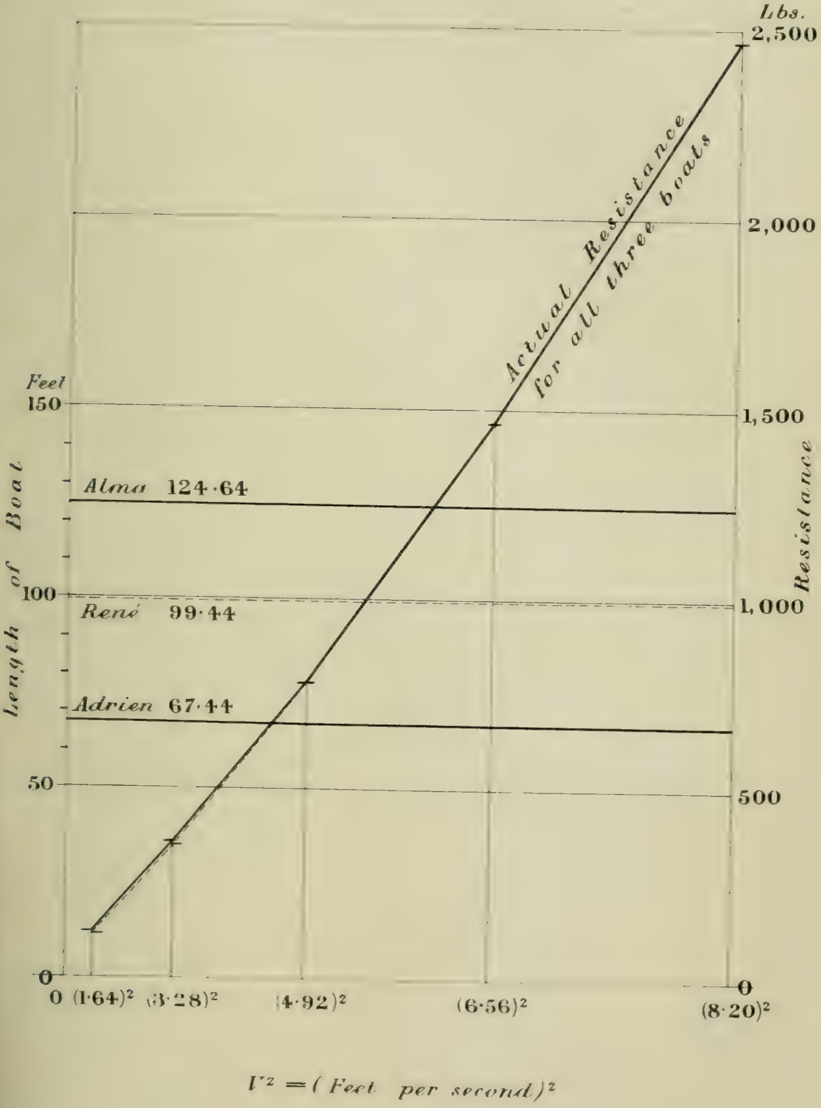
Coefficient of Resistance to traction in rivers, $R \div \omega V^2$.



Mechanical Engineers 1897.

Table 7.

Resistance independent of length of boat.



CANAL-BOAT PROPULSION. *Plate 33.*

Table 8.

Lbs. Resistance to traction in Canal and in River. Lbs.

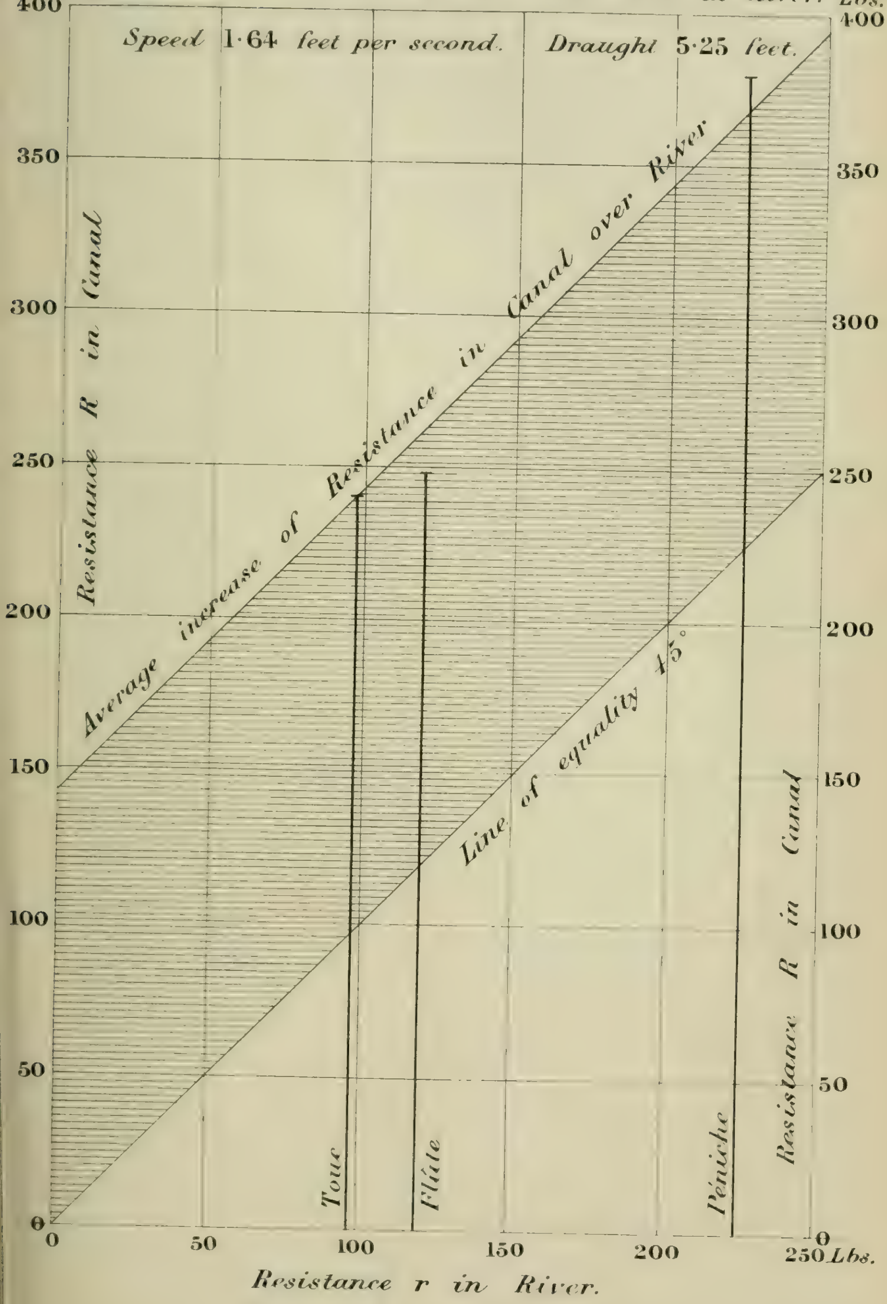
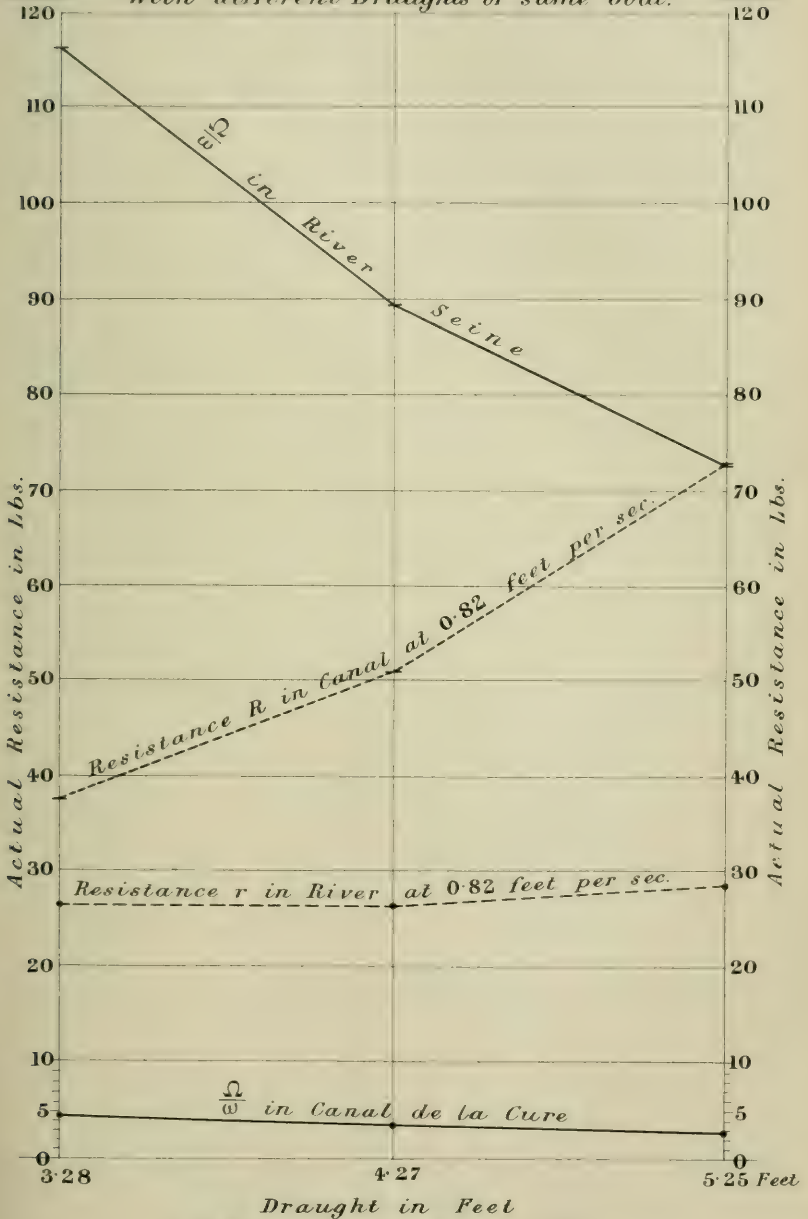


Table 10.

Ratio $\frac{\Omega}{\omega}$ $\frac{\textit{wetted section of waterway}}{\textit{immersed midship section of boat}}$

and Resistance to traction in Canal and in River,
with different Draughts of same boat.



Mechanical Engineers 1897.

CANAL-BOAT PROPULSION. *Plate 35.*

Table 10.

Resistance R in Canal de la Cure,
and Resistance r in River Seine,
with different Draughts of same boat.

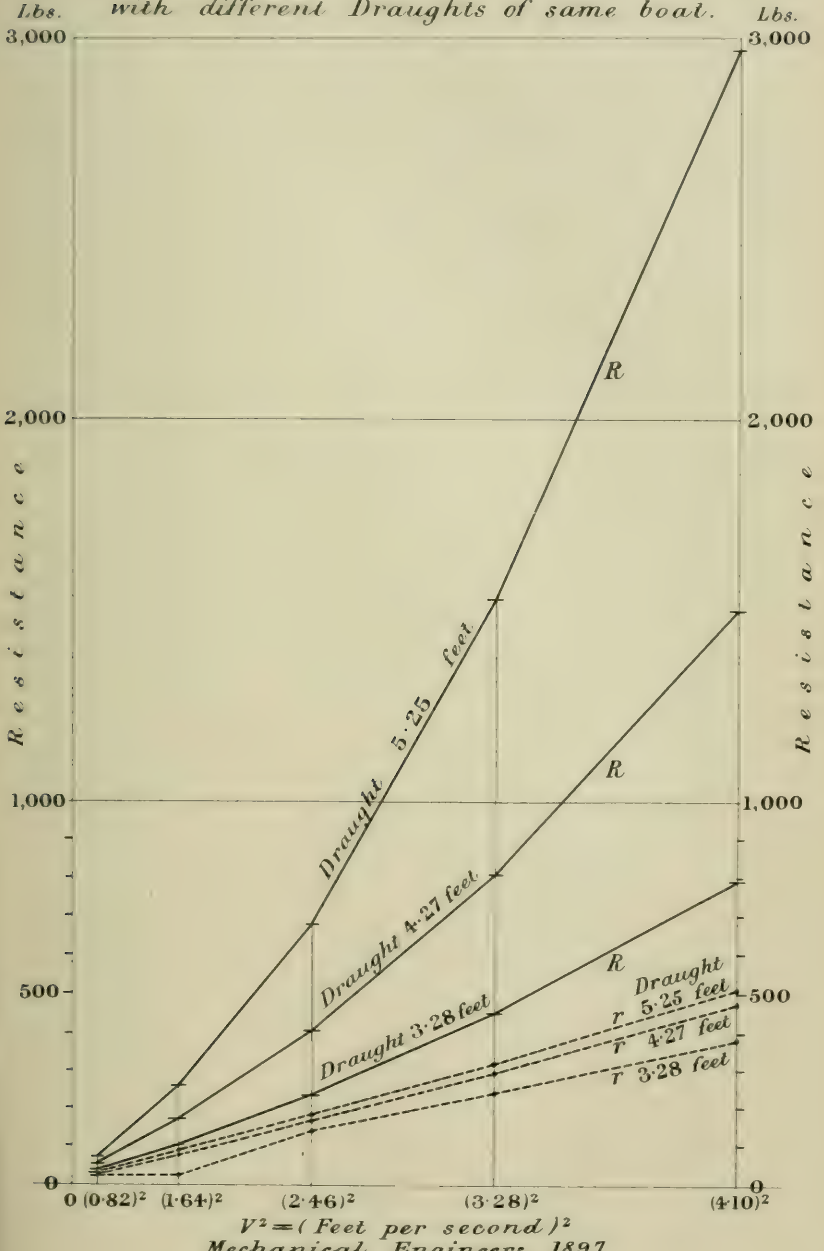
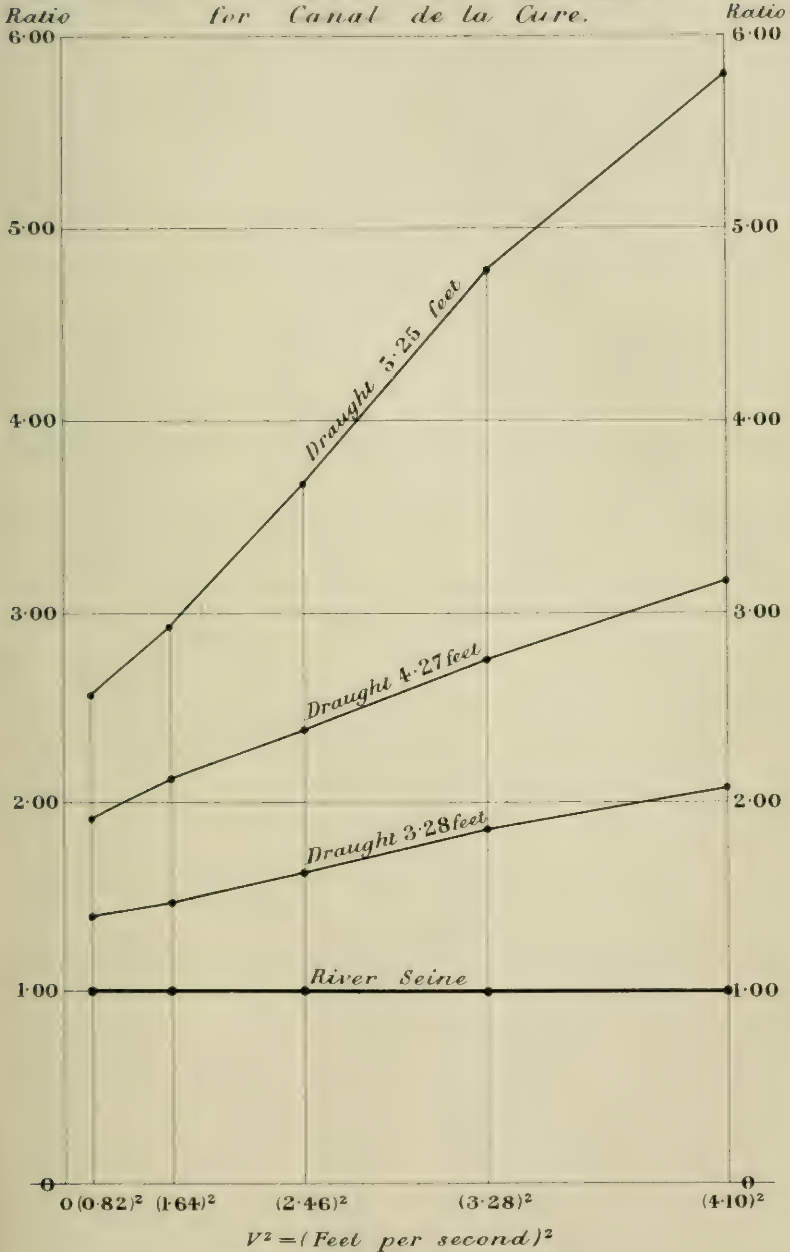


Table 10.

Ratio of Resistances $\frac{R}{r}$ *in Canal / in River*

for Canal de la Cure.



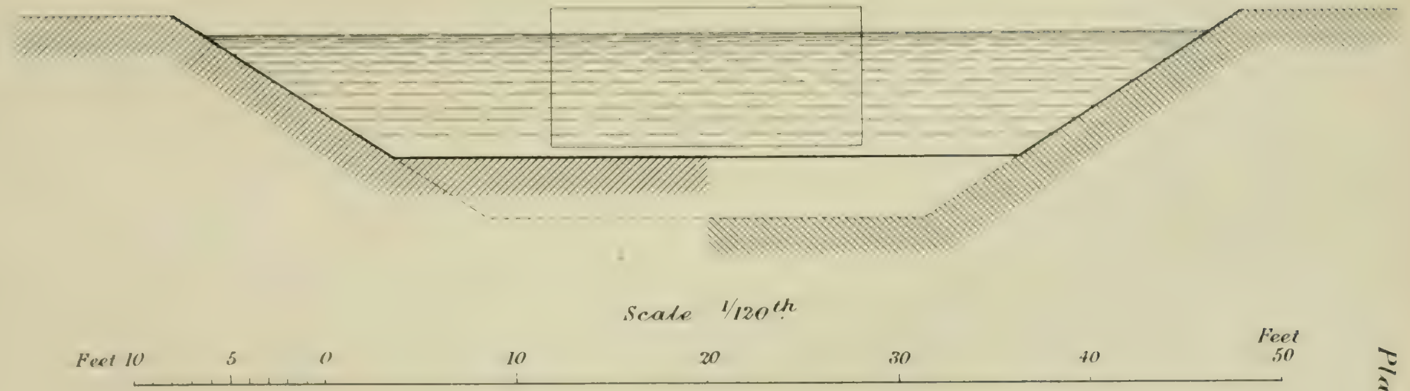
V^2 = (Feet per second)^2

Mechanical Engineers 1897.

CANAL-BOAT PROPULSION.

Plate 37.

Normal Section of French Canals.



Scale $^1/_{120}$th.

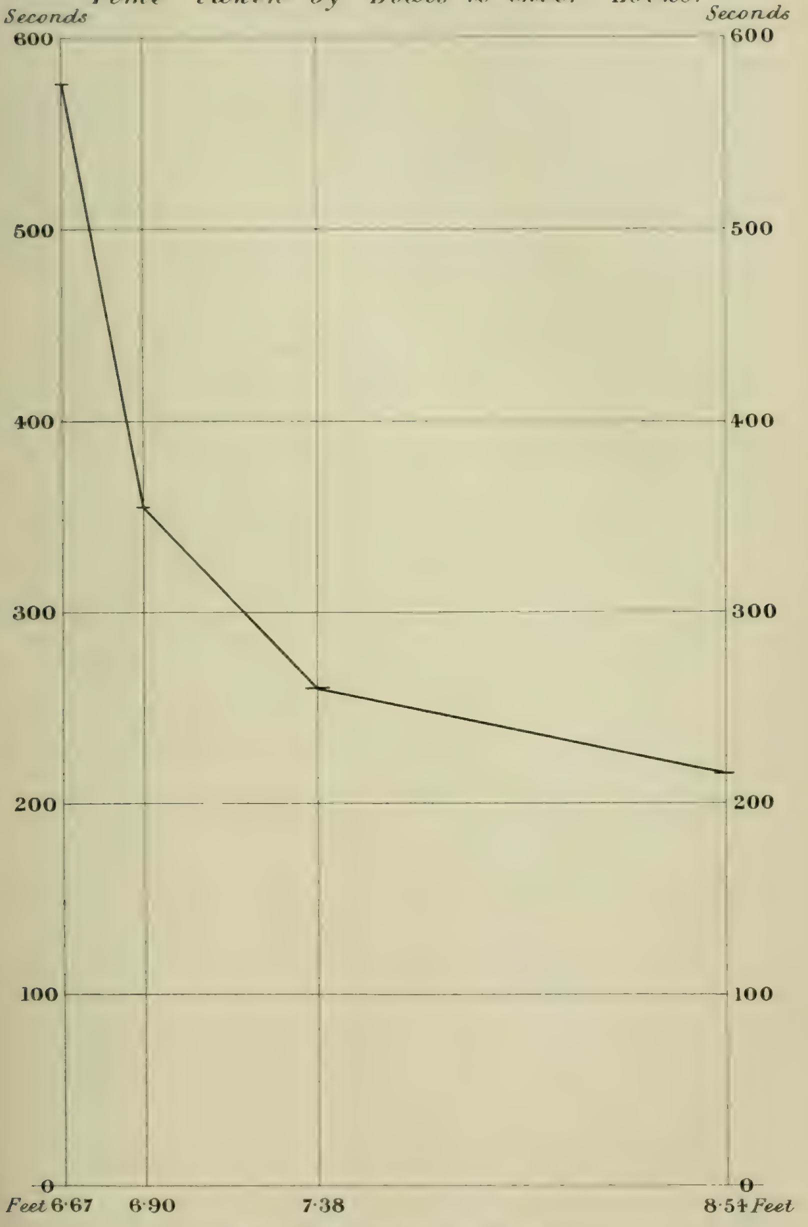
Mechanical Engineers 1897.

Plate 37.

CANAL-BOAT PROPULSION. *Plate 38.*

Table II.

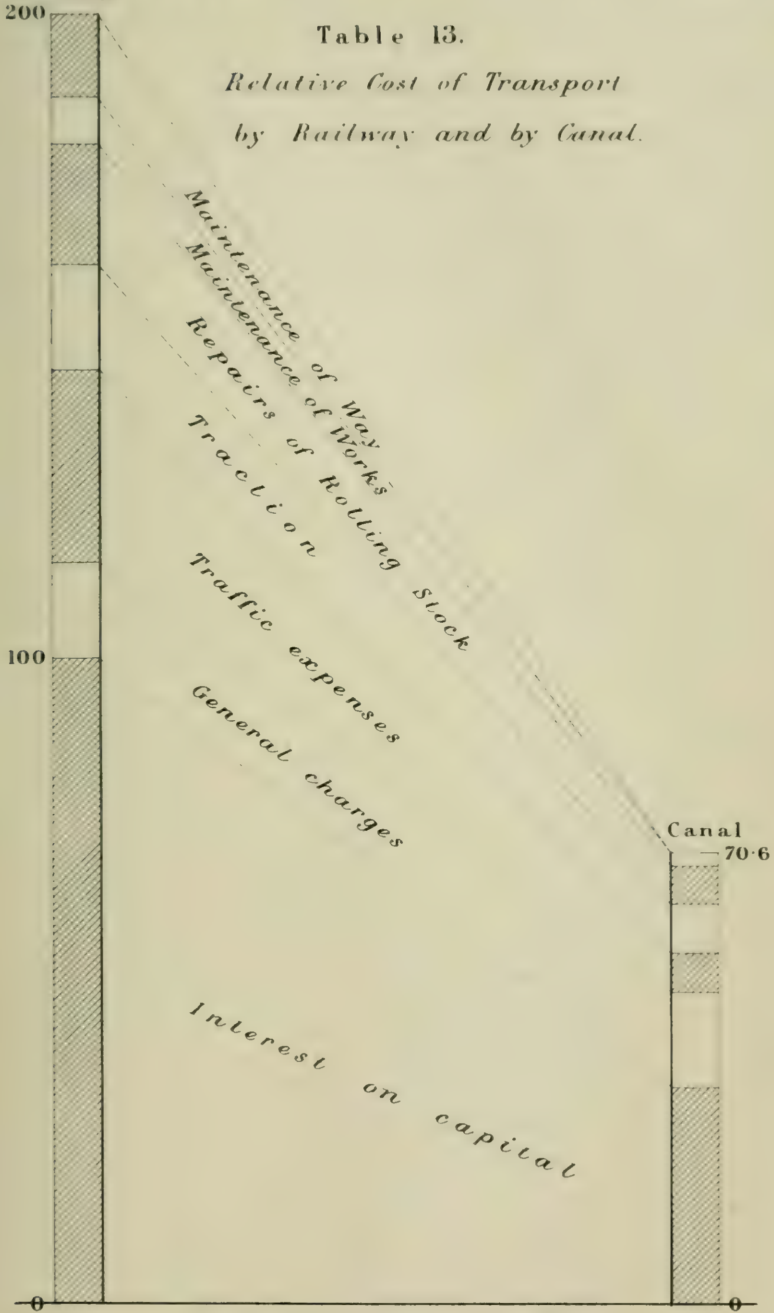
Time taken by Boats to enter Locks.



Mechanical Engineers 1897.

Table 13.

Relative Cost of Transport by Railway and by Canal.



CANAL-BOAT PROPULSION.

Hydraulic Propulsion with Capell Centrifugal Pump.

Fig: 3.
Transverse Section.

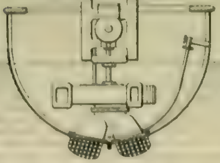


Fig: 1. *Longitudinal Section.*

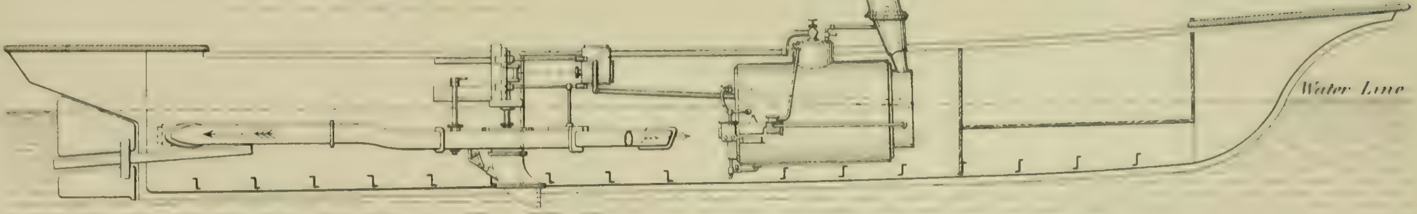
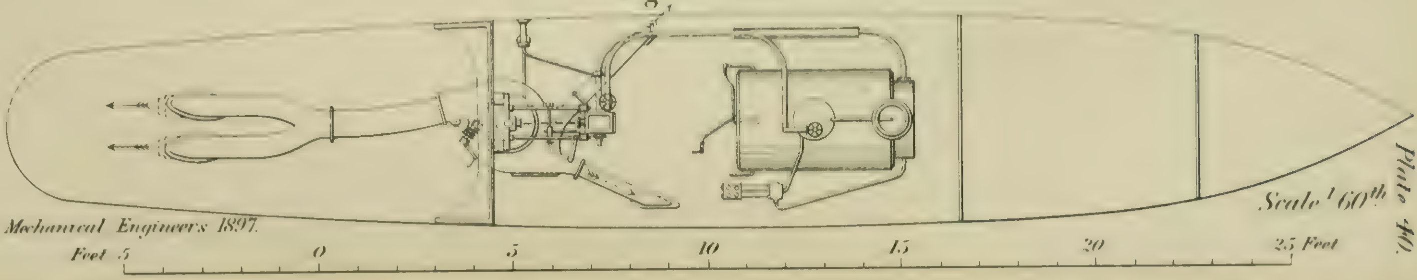


Fig: 2. *Plan.*



Scale 1/60th

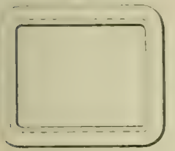
Mechanical Engineers 1897.

Plate 40.

CANAL-BOAT PROPULSION. *Plate 41.*

Hydraulic Propulsion.

Fig: 5.
Discharge orifice A.



Capell Hydraulic Turbine.

Fig: 6.
Discharge orifices F F.

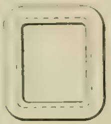


Fig. 4.
Sectional Plan.

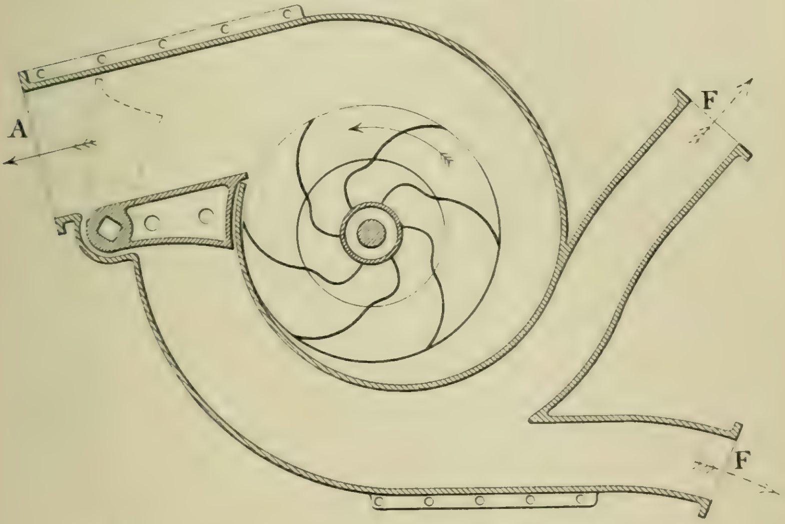
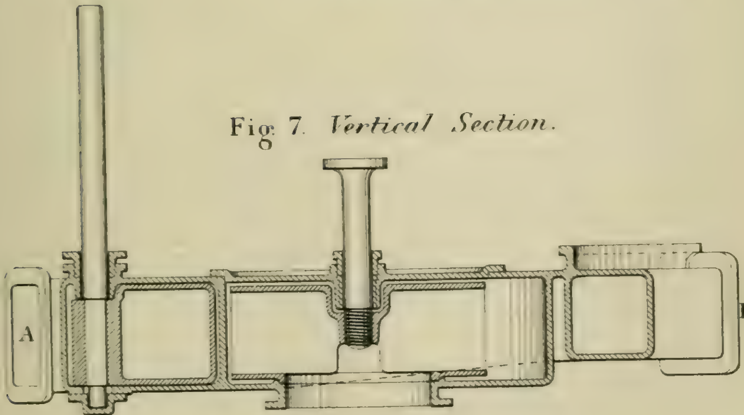


Fig. 7. *Vertical Section.*



Mechanical Engineers 1897.

Scale $^1/_{12}$*th*

Inches 10 5 0 10 20 30 *Inches*

CANAL-BOAT PROPULSION.

Hydraulic Propulsion.

Capell Hydraulic Turbine.

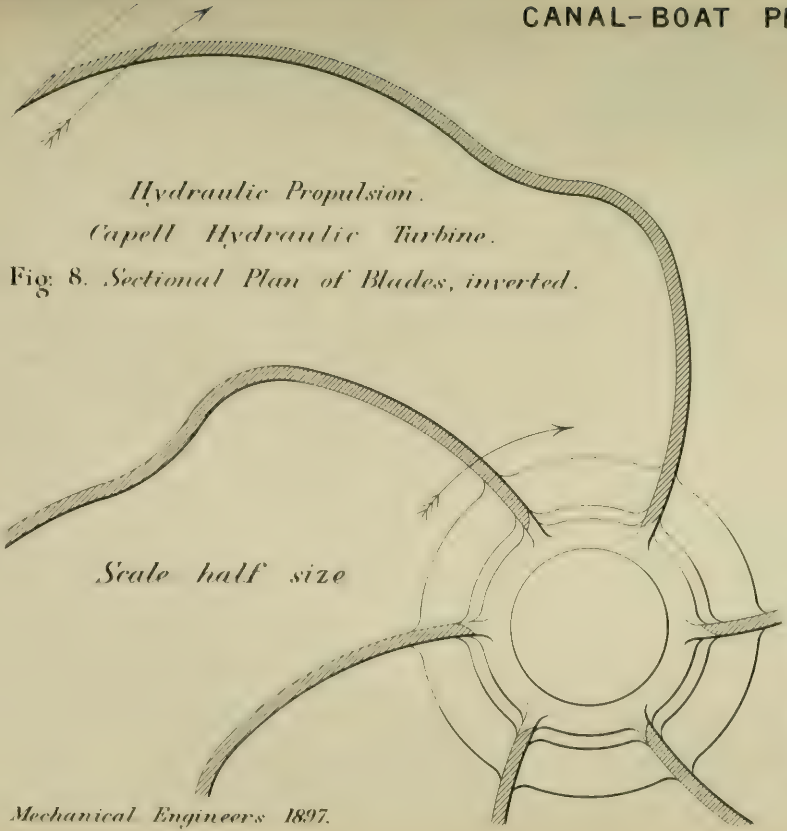


Fig: 8. Sectional Plan of Blades, inverted.

Scale half size

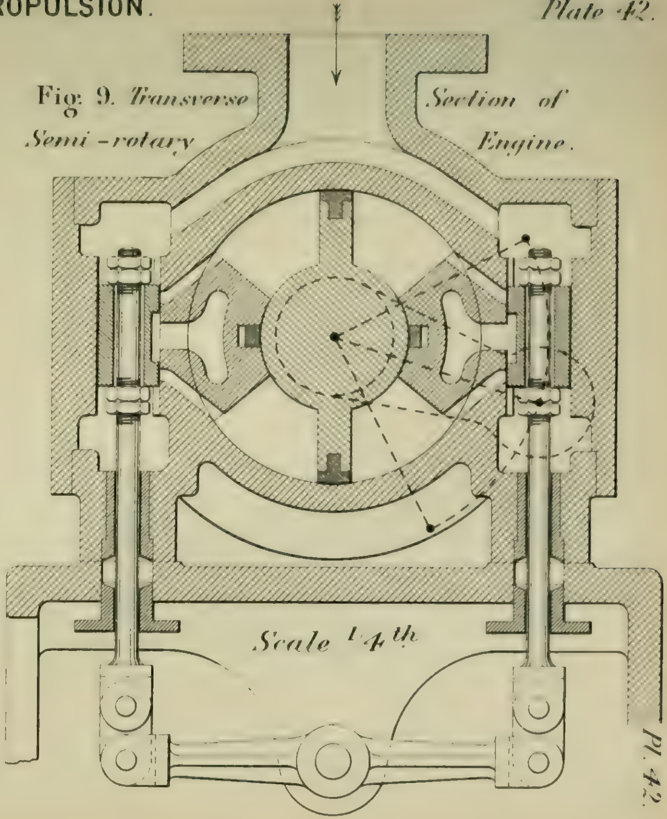


Fig: 9. Transverse Section of Semi-rotary Engine.

Scale 1/4th.

CANAL-BOAT PROPULSION. *Plate 43.*

Hydraulic Propulsion.

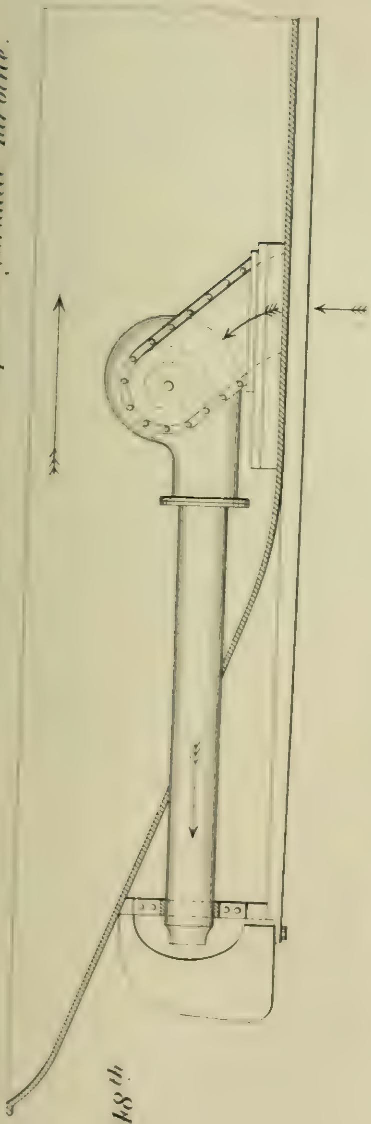


Fig: 10. *Single central discharge pipe from Capell Hydraulic Turbine.*

Scale 1/48th.

Nozzles of discharge pipes.

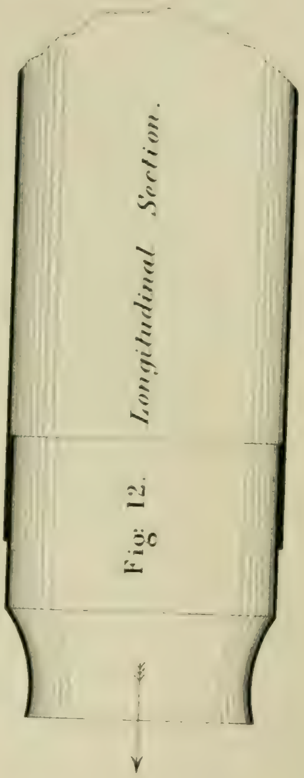


Fig: 12. *Longitudinal Section.*

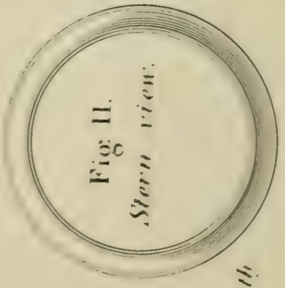


Fig: 11. *Stern view.*

Scale 1/4th.

CANAL-BOAT PROPULSION.

Plate 44.

Experiments on Screw and Hydraulic Propulsion.

Fig. 13. *Indicated Horse-Power, and Speed of boat.*

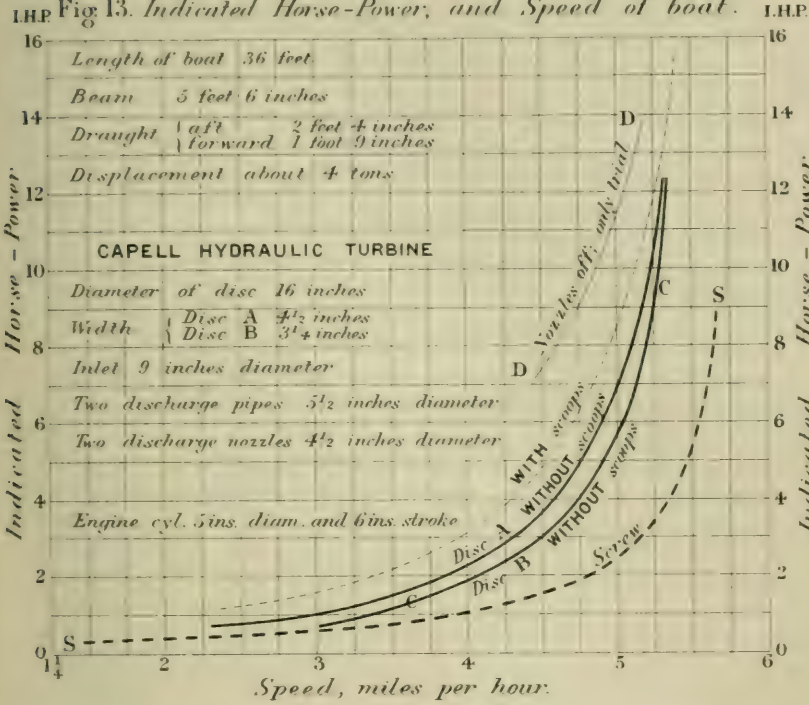
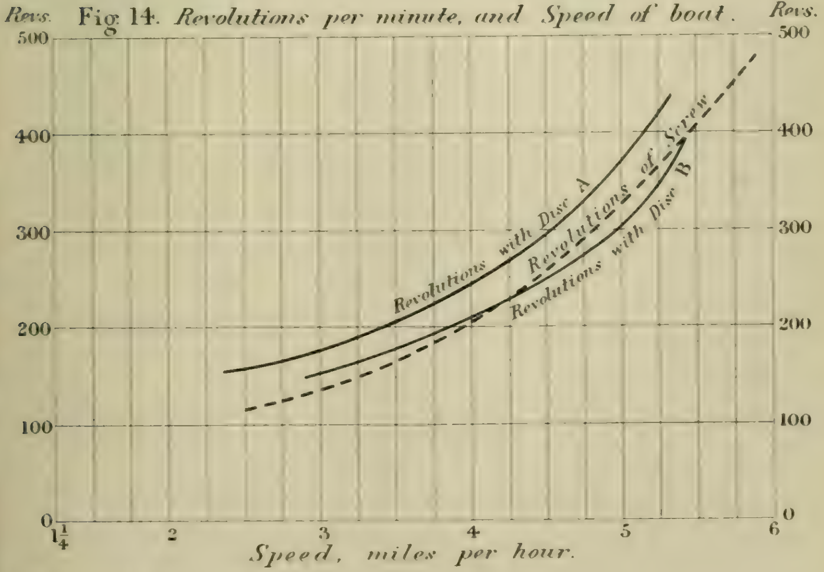
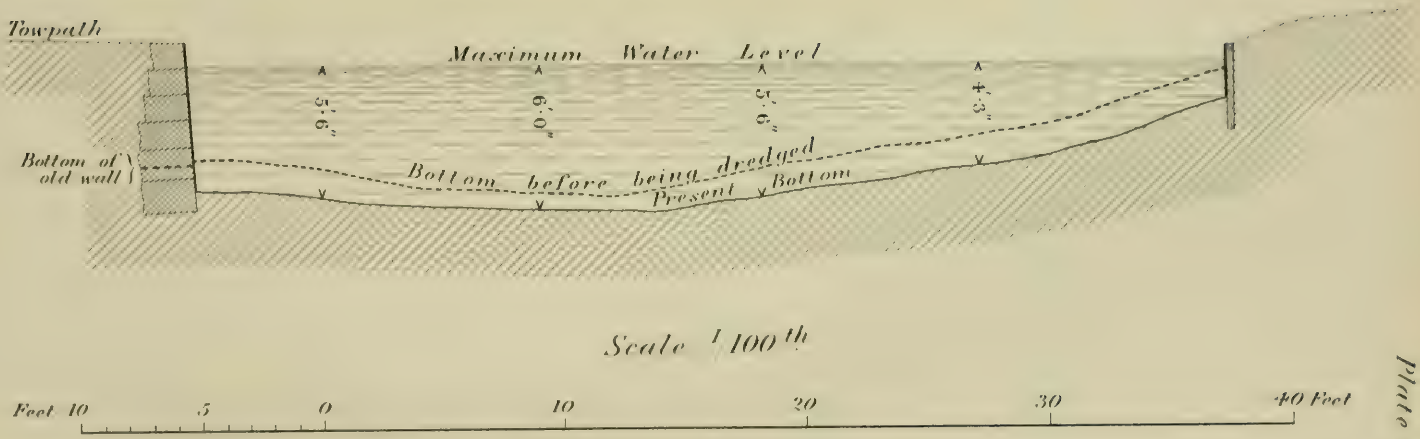


Fig. 14. *Revolutions per minute, and Speed of boat.*



CANAL-BOAT PROPULSION.

Average Cross Section of Bridgewater Canal.



Scale 1/100th

Plate 45.

THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1897.

PARTS 3–4.

PUBLISHED BY THE INSTITUTION,
19 VICTORIA STREET, WESTMINSTER, S.W.

The right of Publication and of Translation is reserved

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1897.

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PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71. (*Deceased* 1897.)

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79.

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86.

Sir Edward H. Carbutt, Bart., 1887–88.

Charles Cochrane, 1889.

Joseph Tomlinson, 1890–91. (*Deceased* 1894.)

Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93.

Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.

The Institution of Mechanical Engineers.

OFFICERS.

1897.

PRESIDENT.

E. Windsor Richards,	Low Moor.

PAST-PRESIDENTS.

Sir William Anderson, K.C.B., D.C.L., F.R.S.,	Woolwich.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Jeremiah Head,	London.
Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
John Robinson,	Leek.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S.,	London.
Samuel W. Johnson,	Derby.
Francis C. Marshall,	Newcastle-on-Tyne.
Edward P. Martin,	Dowlais.
William H. Maw,	London.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
Henry Davey,	London.
William Dean,	Swindon.
Sir Benjamin A. Dobson,	Bolton.
Bryan Donkin,	London.
John Hopkinson, Jun., D.Sc., F.R.S.,	London.
Arthur Keen,	Birmingham.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Henry D. Marshall,	Gainsborough.
Thomas Mudd,	West Hartlepool.
James Platt,	Gloucester.
John I. Thornycroft, F.R.S.,	London.
A. Tannett Walker,	Leeds.
Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

TREASURER.

Harry Lee Millar.

SECRETARY.

Alfred Bache,

The Institution of Mechanical Engineers, 19 *Victoria Street, Westminster, S.W*

[Telegraphic address:—*Mech, London.* Telephone:—*Westminster,* 264]

Institution of Mechanical Engineers.

ESTABLISHED 1847.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1897.

HONORARY LIFE MEMBERS.

1890. H. R. H. Albert Edward, Prince of Wales, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pall Mall, London, S.W.

1892. Field Marshal H.R.H. the Duke of Cambridge, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Gloucester House, Park Lane, London, W.

1883. Abel, Sir Frederick Augustus, Bart., K.C.B., D.C.L., D.Sc., F.R.S., The Imperial Institute, Imperial Institute Road, London, S.W.; and 2 Whitehall Court, London, S.W. [*Imperial Institute, London.* 8743.]

1878. Crawford and Balcarres, The Right Hon. the Earl of, K.T., F.R.S., 2 Cavendish Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1889. Eiffel, Gustave, 37 Rue Pasquier, Paris.

1888. Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., Trinity College, Dublin.

1883. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 17 Victoria Street, Westminster, S.W. [*Kinematic, London.*]

1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1897. Roberts-Austen, William Chandler, C.B., D.C.L., F.R.S., Professor of Metallurgy, Royal College of Science; Chemist of the Royal Mint, Tower Hill, London, E.

1888. Rosse, The Right Hon. the Earl of, K.P., D.C.L., LL.D., F.R.S., Birr Castle, Parsonstown, Ireland.

1896. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

MEMBERS.

1890. Abbott, Arthur Harold, care of Messrs. Octavius Steel and Co., Calcutta, India: (or care of F. C. Abbott, 101 Lambeth Palace Road, London, S.E.)

1878. Abbott, Thomas, Newark Boiler Works, Newark [*Abbott, Newark.*]; and Arlington House, Retford.

1883. Abbott, William Sutherland, Superintendent and Chief Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, Lime Villa, South Woodford, Essex.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 28 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1894. Accles, William Sloane, 39 Victoria Street, Westminster, S.W.

1892. Acland, Captain Francis Edward Dyke, 76 Cheapside, London, E.C. [*Onager, London.* 15252.]

1897. Adams, Edwin, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1897. Adamson, Daniel, Works Manager, Messrs. Joseph Adamson and Co., Hyde, near Manchester.

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1889. Addy, George, Waverley Works, Sheffield. [*Milling, Sheffield.*]

1887. Ahmed Pasha, Rear Admiral, Engineer-in-Chief and Head of Technical Inspecting Commission, Imperial Naval Arsenal, Constantinople.

1891. Ahrbecker, Henry Conrad Vandepoel, Morts Dock and Engineering Co., Balmain, Sydney, New South Wales.

1893. Ainley, Henry, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1886. Aisbitt, Matthew Wheldon, 47 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1885. Alderson, George Beeton, Messrs. Allen, Alderson and Co., Alexandria, Egypt; Norland House, Ramleh, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, Milton, Northamptonshire.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Co., Albert Works, Penistone Road, Sheffield.

1874. Allen, Francis, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1891. Allen, Marcus, Union Brass and Iron Works, Great Ancoats Street, and Phœnix Iron Works, Jersey Street, Manchester [*Valves, Manchester. Nat.* 60]; and The Nest, Knutsford.

1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.

1885. Allen, William Henry, Messrs. W. H. Allen Son and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]; and Queen's Engineering Works, Bedford. [*Pump, Bedford.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, 11 Avenue Victoria, Scarborough.

1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Allott, Charles Sneath, 46 Brown Street, Manchester. [*Allotted, Manchester. Nat.* 1952.]

1876. Allport, Charles James, 12 Tavistock Square, London, W.C.; and Whitehall Club, Parliament Street, Westminster, S.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, General Manager, La Guaira and Caracas Railway, Caracas, Venezuela: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and Eastdene, St. James' Road, Sutton, Surrey. [*Drilling, London.*]

1867. Amos, James Chapman, Rose Cottage, Fairfax Road, Teddington, S.O., Middlesex.

1891. Anderson, Alexander Southerland, Chief Engineer, Ordnance Department, Ordnance Factory, Cawnpore, India.

1880. Anderson, Edward William, Messrs. Easton, Anderson and Goolden, Erith Iron Works, Erith, S.O., Kent; and Roydon Lodge, Erith, S.O., Kent.

1890. Anderson, Herbert William, Messrs. Hilton Anderson and Co., Manor Works, Halling, near Rochester.

1892. Anderson, John Wemyss, Walker Engineering Laboratories, University College, Liverpool.

1894. Anderson, Tom Scott, Royal Insurance Buildings, Sheffield; and 8 Southbourne Road, Victoria Park, Sheffield.

1856. Anderson, Sir William, K.C.B., D.C.L., F.R.S., Director-General of Ordnance Factories, 6 Royal Arsenal, Woolwich.

1891. Anderson, William, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1892. Andrew, Thomas, Rand Club, Johannesburg, Transvaal, South Africa.

1895. Andrews, Thomas, Messrs. Andrews and Baby, Welsh Wagon Works, East Moors, Cardiff. [*Wagons, Cardiff.* 693.]

1893. Angas, William Moore, Jacksonville, Florida, United States: (or care of G. Douglas Angas, Neswick, Bainton, Hull.)

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1883. Appleby, Percy Vavasseur, Messrs. Jessop and Appleby Brothers, 22 Walbrook, London, E.C. [*Millwright, London.*]

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1891. Archbold, John, Eastwood Collieries, Eastwood, R.S.O., Notts.

1881. Archbold, Joseph Gibson, Manager, Blyth Dry Dock, Blyth, Northumberland.

1874. Archer, David, 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.

1894. Armour, James Glencairn, Cereal Court (A), Brunswick Street, Liverpool.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1866. Armstrong, George, Locomotive Department, Great Western Railway, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1894. Arnot, William, 79 West Regent Street, Glasgow. [*Induction, Glasgow. 5341.*]

1887. Arrol, Sir William, M.P., LL.D., Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, 1320 Artes, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 55 and 56 Bishopsgate Street Within, London, E.C.)

1873. Ashbury, Thomas (*Life Member*), 17 St. Ann's Square, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Tardeo, Bombay, India.

1895. Ashcroft, Andrew George, Principal, Woolwich Polytechnic, William Street, Woolwich; and 6 St. Margaret's Road, Plumstead.

1890. Ashley, Thomas James, Messrs. McNeill and Co., Samarang, Java.

1891. Ashworth, Henry, The Villa, Llangorse, Talgarth, R.S.O., Breconshire.

1890. Askham, John Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1890. Askham, Philip Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1891. Asplen, Bernard, Southall: (or care of W. W. Asplen, Foxton Hall, Royston, Cambridgeshire.)

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1890. Aston, John W., Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham; and Municipal Technical School, Birmingham.

1889. Atkinson, Alexander, Jammu, Kashmir, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1875. Atkinson, Edward (*Life Member*), 32 Park Road, West Dulwich, London, S.E.

1890. Atkinson, Edward Turner, London County Council, Spring Gardens, London, S.W.

1892. Atkinson, James, The Woodlands, Marple, near Stockport.

1897. Atsumi, Sadamoto, Superintendent Engineer, Osaka Shosen Kaisha, Tomijima Cho, Kitaku, Osaka, Japan.

1892. Ault, Edwin, 47 Victoria Street, Westminster, S.W.

1892. Austin, James Meredith, Messrs. R. E. Crompton and Co., Arc Works, Chelmsford; and 2 Prospect Terrace, Springfield, Chelmsford.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1897. Avery, William Beilby (*Life Member*), Messrs. W. and T. Avery, Soho Foundry and Digbeth, Birmingham.

1891. Bagshaw, Walter, Victoria Foundry, Batley.

1885. Bailey, Sir William Henry, Albion Works, Salford, Manchester [*Beacon, Salford.*]; and Sale Hall, Cheshire.

1872. Bailly, Philimond, 282 Rue Royale, Bruxelles, Belgium.

1890. Bain, George, Locomotive Department, Egyptian Government Railways, Cairo, Egypt.

1880. Bain, William Neish, 40 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]

1869. Bainbridge, Emerson, M.P., Nunnery Colliery Offices, New Haymarket, Sheffield; and 4 Whitehall Court, London, S.W.

1890. Baker, Sir Benjamin, K.C.M.G., LL.D., F.R.S. (*Life Member*), 2 Queen Square Place, Westminster, S.W.

1897. Baker, George Samuel, Messrs. Joseph Baker and Sons, Willesden Junction, London, N.W. [*Mapleleaf, London.* 7463.]

1896. Baker, William Henry, Superintendent of Works, Residency Post Office, Gwalior, Central India.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1893. Baldwin, Alfred, M.P., Wilden Iron Works, Stourport.

1894. Baldwin, Arthur Hugh, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.* Nat. 330; Mutual 1330.]

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1897. Balkwill, Alfred John, Works Manager, Messrs. E. Green and Son, Economiser Works, Wakefield.

1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.

1892. Banister, George Henry, Carriage Department, Royal Arsenal, Woolwich.

1888. Barker, Eric Gordon, Locomotive Superintendent, Wirral Railway, Dock Station, Birkenhead; and Guyse House, Oxton, R.O., near Birkenhead.

1896. Barker, Matthew Wilson, P.O. Box 1463, Johannesburg, Transvaal, South Africa.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham. [*Gasengine, Birmingham.* 2530.]

1880. Barlow-Massicks, Thomas, The Oaks, Millom, Cumberland.

1891. Barnes, John Edward Lloyd, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1881. Barnett, John Davis, Assistant Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.

1887. Barningham, James, 41 Victoria Buildings, Victoria Street, Manchester.

[illegible]84. Barr, Archibald, D.Sc., Professor of Engineering, The University, Glasgow.

18[illegible]. Barrett, John James, 5 Chinchpoogly Road, Bombay, India.

1885. B[illegible]ie, William, Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., 266 Bluff, Yokohama, Japan.

1887. Barringer, Herbert, 88 Bishopsgate Street Within, London, E.C.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1871. Barry, Sir John Wolfe, K.C.B., F.R.S., 21 Delahay Street, Westminster, S.W. [*Consilium, London.* 3024.]

1883. Bartlett, James Herbert, Middlesbrough, Kentucky, United States.

1887. Bate, Major Charles McGuire, R.E., Royal Engineers' Office, Mauritius.

1885. Bateman, Henry, Superintendent, Municipal Fire Brigade and Stores, Rangoon, India.

1896. Bateman, James Thomas, Fair View, Bebington, near Birkenhead.

1891. Bates, Henry, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester; and 30 Halliwell Terrace, Trafford Road, Salford, Manchester.

1892. Baxter, Peter Macleod, Messrs. McKie and Baxter, Copland Works, Govan, Glasgow.

1889. Bayford, William James, Engineer and Manager, Messrs. Meakin and Co., Brewers, Delhi, India.

1872. Bayliss, Thomas Richard, Belmont, Northfield, Birmingham.

1891. Baynes, John, Midland Railway-Carriage and Wagon Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1877. Beale, William Phipson, Q.C., 10 New Court, Carey Street, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1895. Beard, Bernard, Messrs. Francis Morton and Co., Hamilton Iron Works, Garston, near Liverpool.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1893. Beare, Thomas Hudson, F.R.S.E., Professor of Engineering, University College, Gower Street, London, W.C.

1893. Beastow, William Henry, Messrs. Brooks and Doxey, Union Iron Works, West Gorton, Manchester; and Junction Iron Works, Miles Platting, Manchester; and 157 Hyde Road, West Gorton, Manchester.

1891. Beatty, Hazlitt Michael, Chief Locomotive Superintendent, Cape Government Railways, Cape Town, Cape Colony; and Roselare Camp Ground, Rondebosch, near Cape Town, Cape Colony.

1880. Beaumont, William Worby, Outer Temple, 222 Strand, London, W.C. [*Vibromotor, London.*]

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, 313 Hainault Road, Leytonstone, London, N.E.

1875. Beckwith, John Henry, Messrs. Galloways, Knott Mill Iron Works, Manchester; and 48 Scarisbrick Road, Southport.

1882. Bedson, Joseph Phillips, Parkhurst, Middlesbrough.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough; and Linthorpe, Middlesbrough. [*Bells, Middlesbrough.* 5510.]

1897. Bell, Captain Charles Thornhill, R.A., Officiating Superintendent, Gun Carriage Factory, Madras, India.

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1897. Bellamy, Alfred Rowe, Managing Director, Messrs. J. E. H. Andrew and Co., Reddish, near Stockport.

1868. Belliss, George Edward, Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham [*Belliss, Birmingham.*]; and The Dell, King's Norton, near Birmingham.

1897. Belliss, John, Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1895. Benn, Sykes, Messrs. S. S. Stott and Co., Haslingden, near Manchester. [*Elevator, Haslingden.* 103.]

1894. Bennett, James William, Messrs. Taylor and Lawson, Engineering Works, Batavia; and Harwood, Branksome Park, Bournemouth.

1895. Bennington, John William, Fleet Engineer, R.N., H.M.S. "Hermione," Devonport.

1895. Bennion, Charles, Messrs. Pearson and Bennion, Union Works, Leicester; and Danes Hill House, Hinckley Road, Leicester. [*Prominent, Leicester.* 103.]

1894. Bentley, George, Messrs. Bentley and Jackson, Lodge Bank Works, Bury, Lancashire.

1895. Berchem, Alphonse Henry Emanuel, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.

1890. Berkley, James Eustace, Messrs. George Berkley and Co., 13 Sirdar's Palace, Apollo Street, Bombay, India.

1878. Berrier-Fontaine, Marc, Directeur des Constructions navales, Directeur de l'Établissement national d'Indret, par la Basse Indre, (Loire inférieure), France.

1893. Berry, Henry, Croydon Works, Leeds.

1893. Berry, John Ferrier, care of Messrs. Howard Farrar and Co., P. O. Box 455, Johannesburg, Transvaal, South Africa.

1897. Berthiez, Charles, Works Manager, Ateliers de Constructions Mécaniques ci-devant Ducommun, Mulhouse, Alsace, Germany.

1890. Bertram, Alexander, Messrs. Newton Chambers and Co., Thorncliffe Iron Works and Collieries, near Sheffield.

1891. Bertram, David Noble, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1891. Best, Francis Edward, Bacis Gold and Silver Mines, viâ Gavilanes, Durango, Mexico: (or 1 Swan Walk, Chelsea Embankment, London, S.W.)

1893. Betts, Samuel, Locomotive Superintendent, Oxelösund-Fleu-Westmanlands Railway, Eskilstuna, Sweden.

1891. Bevis, Alfred William, Brunswick Villa, Malvern Road, Acock's Green, Birmingham.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1892. Bickle, Thomas Edwin, Messrs. Bickle and Co., Great Western Docks, Plymouth. [*Engineers, Plymouth.* 176.]

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, 17 Russell Street, Bath.

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1897. Billetop, Torben Christian, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1888. Billinton, Robert John, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1890. Bingham, Charles Henry, Messrs. Walker and Hall, Electro Works, Howard Street, Sheffield. [*Bingham, Sheffield.*]

1887. Binnie, Sir Alexander Richardson, Engineer, London County Council, Spring Gardens, London, S.W.; and 77 Ladbroke Grove, Notting Hill, London, W.

1891. Bird, George, Messrs. James Bartle and Co., Western Iron Works, Notting Hill, London, W.

1897. Bird, William Hobart, Hearsall House, Coventry.

1880. Birkett, Herbert, 91 Victoria Street, Westminster, S.W.

1897. Black, James Mark, Board of Trade Surveyor, Board of Trade Office, Londonderry.

1896. Black, Peter Blair, 185 Palmerston Buildings, Old Broad Street, London, E.C. [*Blackness, London.*]

1879. Black, William, 1 Lovaine Place, Newcastle-on-Tyne.

1891. Black, William, Eaglescliffe, Newport Road, Cardiff.

1891. Blackburn, Arthur Henry, Fuel Economizer Co., Matteawan, New York, United States.

1891. Blackburn, George William, Messrs. T. Green and Son, Smithfield Iron Works, Leeds.

1890. Blackburn, John, Resident Engineer, Colne Valley Water Works, Bushey, Watford.

1862. Blake, Henry Wollaston, F.R.S., 8 Devonshire Place, London, W.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, Messrs. John Penn and Sons, Greenwich, London, S.E.

1892. Blechynden, John, General Manager, Shanghai Engineering, Shipbuilding and Dock Company, Shanghai, China. [*Steam, Shanghai.*]

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, Catherine Chambers, 8 Catherine Street, Strand, London, W.C.

1884. Bocquet, Harry Claude, Llanwye, Hampton Park, Hereford.

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1895. Bond, George Creswell, Newcastle Chambers, Nottingham. [*Bonds, Nottingham.* 441.]

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1895. Boorman, Joseph Ashworth, Messrs. Greenwood and Batley, Albion Works, Leeds.

1892. Booth, John William, Union Foundry, Rodley, near Leeds.

1890. Booth, Robert, Messrs. Booth and Ravenshaw, 110 Cannon Street, London, E.C.

1880. Borodin, Alexander, President, Ribinsk Railway; Demidoff pereoulok, 1, St. Petersburg, Russia.

1888. Borrows, William, Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helen's, Lancashire.

1891. Boswell, Samuel, 2 Wentworth Villas, Clarence Road, Longsight, Manchester.

1888. Boulding, Sidney, Messrs. Green and Boulding, 21 Featherstone Street, London, E.C. [*Temperature, London.*]

1886. Boult, Alfred Julius, Messrs. Boult and Wade, 111 Hatton Garden, London, E.C. [*Boult, London.* 2896.]

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1886. Bourne, Thomas Johnstone, Imperial Chinese Railways, Tientsin, China: (or care of Mrs. Bourne, 16 Park Road, Southborough, Tunbridge Wells.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1891. Bousfield, John Ebenezer, 4 South Street, Finsbury, London, E.C. [*Invention, London.* 169.]

1879. Bovey, Henry Taylor, LL.D., Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. Bowen, Edward (*Life Member*), Locomotive and Carriage Superintendent, Porto Alegre and New Hamburg Railway, Rio Grande do Sol, Brazil: (or care of Benjamin Packham, 18 Upper Wellington Road, Brighton.)

1858. Bower, John Wilkes (*Life Member*), Meredale, Rugby Road, Leamington Spa.

1892. Bowker, Arthur F., Engineer, Mid-Kent Water Works, Snodland, S.O., Kent.

1893. Boyd, James Tennant, Lochgarry Lodge, Lenzie, Glasgow.

1890. Boyd, John White, 59 St. Vincent Street, Glasgow. [*Silent, Glasgow.*]

1884. Boyer, Robert Skeffington, 8 Bailey Street, Ton, Pentre, R.S.O., Glamorgan.

1882. Bradley, Frederic, Sandhills, Liverpool; Clensmore Foundry, Kidderminster; and Wolverley House, Southport.

1896. Bradney, Walter, Billiter Buildings, Billiter Street, London, E.C.

1897. Bradshaw, George Theobald Mathew, Locomotive and Resident Engineer, Ballycastle Railway, Ballymoney, Ireland.

1878. Braithwaite, Charles C., Boreham Wood Works, Elstree, Herts. [*Packing, Boreham Wood.*]

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich [*Braithwaite, Westbromwich.*]; and 39 Victoria Street, Westminster, S.W.

1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., LL.D., F.R.S., Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1892. Brand, David Jollie, Messrs. Brand and Dryburgh, Cleveland Foundry and Engine Works, Townsville, North Queensland.

1895. Bratt, Edward Hicks Fraser, Messrs. Bratt and Gibson, Taiping, Perak, Straits Settlements.

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's; and The Laurels, Queen's Park, St. Helen's.

1891. Brewster, Edwin Henry George, 12 Delahay Street, Westminster, S.W.

1890. Brewster, Walter Seckford, Messrs. Beyer Peacock and Co.; Wrentham, Fleet Street, Carlton, near Sydney, New South Wales.

1887. Brier, Henry, Messrs. J. H. Carruthers and Co., Hamilton Street, Polmadie, Glasgow.

1889. Briggs, Charles, care of Robert Briggs, Howden.

1881. Briggs, John Henry, Babcock and Wilcox Boiler Works, Renfrew.

1897. Bright, Charles, F.R.S.E., Imperial Institute, Imperial Institute Road, London, S.W.

1894. Brindley, George Samuel, 3 Awoicho Akasaka, Tokyo, Japan. [*Brindley, Tokyo.*]

1895. Britten, Thomas Johnson, P.O. Box 494, Johannesburg, Transvaal, South Africa.

1891. Broadbent, William, Messrs. Thomas Broadbent and Sons, Central Iron Works, Huddersfield. [*Broadbent, Huddersfield.* 102.]

1896. Broadfoot, Andrew Wilson, Locomotive Superintendent, Great Southern Railway, Albany, Western Australia.

1891. Brock, Cameron William Harrison, care of Roxburghe Press, 15 Victoria Street, Westminster, S.W.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton. [*Lennox, Dumbarton.* 1 and 15.]

1896. Brocklehurst, George, Bridgetown, Barbados, West Indies.

1890. Brodie, John Alexander, 3 Cook Street, Liverpool.

1897. Brodrick, William Holborn, 37 Wellington Street, Hull.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1890. Brogden, Thomas, Messrs. Appleby and Brogden, Sandside, Scarborough

1892. Bromiley, William J., Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1892. Bromly, Alfred Hammond, care of Thomas Hammond, Stanwell Street, Colchester.

1892. Brooke, John Walter, Adrian Iron Works, Lowestoft.

1892. Brooke, Robert Grundy, Messrs. Holden and Brooke, Sirius Works, West Gorton, Manchester. [*Influx, Manchester.*]

1884. Brook-Fox, Frederick George, care of Messrs. Grindlay, Groom and Co., Bombay, India.

1897. Brooks, Samuel Herbert (*Life Member*), Union Iron Works, West Gorton, Manchester.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 15 Hyde Park Gardens, London, W. [*Brotherhood, London.*]

1886. Brown, Andrew, 110 Cannon Street, London, E.C.; and Willis Road, Erith, S.O., Kent. [*Sequence, London.* Bank 647.]

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1891. Brown, Arthur Mogg, P.O. Box 379, Port Elizabeth, South Africa.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Intercolonial Railway of Canada, Moncton, New Brunswick, Canada.

1889. Brown, Captain Frederick Alexander William, R.A., Army Ordnance Department, Haulbowline, Cork Harbour, Ireland.

1881. Brown, George William, Trollhättan, Alexandra Road, Reading. [251.]

1892. Brown, James Fiddes, South Lodge, Claybury, Woodford Bridge, Essex.

1884. Brown, Oswald, 32 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1892. Brown, William, Messrs. Siemens Brothers and Co., Woolwich.

1874. Browne, Tomyns Reginald, Deputy Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or care of Mrs. Browne, care of A. C. Brett, Mozufferpore, East Liss, Hants.)

1874. Bruce, Sir George Barclay, 3 Victoria Street, Westminster, S.W.

1889. Bruce, Robert, 77 Billiter Buildings, London, E.C. [*Tangential, London.*]

1867. Bruce, William Duff, 17 Victoria Street, Westminster, S.W.; and 23 Roland Gardens, South Kensington, London, S.W.

1888. Bruff, Charles Clarke, Coalport China Co., Coalport, near Ironbridge, Salop.

1873. Brunel, Henry Marc, 21 Delahay Street, Westminster, S.W. [3024.]

1892. Brunlees, John, 12 Victoria Street, Westminster, S.W. [3245.]

1887. Brunton, Philip George, Inspector of Ironwork, Public Works Department, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Lea Bridge, Clapton, London, N.E.

1892. Buckley, John T., 36 Cleveland Road, Lytham, R.S.O., Lancashire.

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1895. Buckley, Victor Emanuel, Managing Director, Riga Spinning and Thread Works, Strasdenhof, Riga, Russia.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1896. Buckwell, George William, Board of Trade Offices, Custom House Arcade, Liverpool.

1878. Buddicom, Harry William, Penbedw, Nannerch, near Mold.

1886. Budenberg, Christian Frederick, Messrs. Schäffer and Budenberg, Whitworth Street, London Road, Manchester; and Bowden Lane, Marple, Stockport. [*Manometer, Manchester.* 899.].

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes Cox and Co., 4 Fenchurch Avenue, London, E.C.)

1881. Bulkley, Henry Wheeler, N.Y. Times Building, 41 Park Row, New York, United States.

1884. Bullock, Joseph Howell, General Manager, Pelsall Coal and Iron Works, near Walsall; and The Laburnums, Hill Top, West Bromwich.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1891. Bumsted, Francis Dixon, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Rose Hill, Horrabridge, R.S.O., Devon.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1891. Burgess, Francis Chassereau Boughey, Office of Director General of Railways, Technical Section, Simla, India.

1894. Burke, Michael James, Locomotive and Carriage Superintendent, Morvi Railway, Morvi, India.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1893. Burnes, Thomas, R.N., Homeleigh, Longton Avenue, Sydenham, London, S.E.

1878. Burnett, Robert Harvey, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Messrs. Stevenson and Burstal, 38 Parliament Street, Westminster, S.W.

1896. Burstall, Frederic William, Professor of Engineering, Mason University College, Birmingham.

1890. Burstall, Henry Robert John, Messrs. Burstall and Monkhouse, 14 Old Queen Street, Westminster, S.W. [*Advisedly, London.*]

1884. Butcher, Joseph John, P. O. Box 132, Thompsonville, Connecticut, United States.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1892. Butler, Henry William, 9 Dean Street, Workington.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1891. Butler, James, Victoria Iron Works, Halifax; and Longfield, Halifax.

1888. Butter, Frederick Henry, Carriage Department, Royal Arsenal, Woolwich; and 41 Montpelier Vale, Blackheath, London, S.E.

1891. Butter, Henry Joseph, Messrs. Tannett Walker and Co., Leeds; and Claremont, Burrage Road, Plumstead.

1894. Butterworth, Joseph, Messrs. Lancaster and Tonge, Pendleton, Manchester.

1892. Byrne, Francis Furlong, Dublin Cycle Co., 2 Lower Abbey Street, Dublin. [*Mermaid, Dublin.*]

1887. Caiger, Emery John, Messrs. E. J. Caiger and Co., 92 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1886. Cairnes, Frederick Evelyn, Bridgewater Hotel, Worsley, near Manchester.

1889. Callan, William, River Plate Fresh Meat Co., 2 Coleman Street, London, E.C.

1886. Cambridge, Henry, Stuart Chambers, Mount Stuart Square, Cardiff.

1893. Campbell, Andrew Chisholm, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1877. Campbell, Angus, Logie, Mussoorie, N. W. Provinces, India.

1880. Campbell, Daniel, Messrs. Campbell, Macmaster and Co., 11 and 12 Clement's Lane, Lombard Street, London, E.C. [*Duke, London.* 2011.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1893. Campbell, James Alexander Miller, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1892. Campbell, William Walker, Messrs. Campbell and Calderwood, Soho Engine Works, Paisley. [*Soho, Paisley.* 162.]

1885. Capito, Charles Alfred Adolph, Rushbourne, St. Lawrence-on-Sea, Thanet; and 13 Victoria Street, Westminster, S.W.

1892. Capper, David Sing, Professor of Mechanical Engineering, King's College, Strand, London, W.C.

1860. Carbutt, Sir Edward Hamer, Bart., 19 Hyde Park Gardens, London, W.; and Nanhurst, Cranleigh, Guildford.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Burma Railways Co., Insein, Burma.

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1892. Carnegie, David, Royal Laboratory, Royal Arsenal, Woolwich.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, 1 West Pier, London Docks, London, E.

1895. Carr, Robert Alfred, 1 West Pier, London Docks, London, E.

1892. Carrack, Charles, Messrs. Crossley Brothers, 116 New Street, Birmingham.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Hall Garth, Coatham Mundeville, Darlington. [*Wardale, Gateshead.*]

1885. Carter, Herbert Fuller, Calle de Gante 11, Ciudad de Mexico, Mexico: (or care of H. Maynard Carter, 79 Wool Exchange, Coleman Street, London, E.C.)

1877. Carter, William, General Manager, The Hydraulic Engineering Company, Chester.

1888. Castle, Frank, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Caswell, Samuel John, care of Messrs. A. C. Sim and Co., 18 Concession, Kobe, Japan.

1892. Causer, William George, Brighton Villa, Handsworth, R.O., Birmingham.

1883. Cawley, George, 29 Great George Street, Westminster, S.W.

1892. Chadwick, Osbert, C. M. G., Crown Agents' Department, Colonial Office, Downing Street, London, S.W.; and 11 Airlie Gardens, Kensington, London, W.

1894. Chaffey, George, P.O. Box 75, Mildura, Victoria.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1889. Challen, Walter Bernard, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1892. Chalmers, George, St. John del Rey Mining Co., 28 Tower Chambers, Finsbury Pavement, London, E.C.

1886. Chalmers, John Reid, 18 Hemingford Road, Barnsbury, London, N.

1897. Chambers, Edward John, Managing Director, Messrs. Bullers, Tipton.

1896. Chambers, Robert Martin, Messrs. Chambers and Co., Cuba Street, Belfast.

1890. Chandler, Noel, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1888. Chapman, Arthur, Assam Railways and Trading Co., 1 Clive Ghat Street, Calcutta, India; The New Club, Calcutta, India: (or Hulne Park, Alnwick.)

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W. [*Tubalcain, London.*]; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.; and St. Mildred's, Lovelace Gardens, Surbiton.

1893. Charlesworth, Sheard, Messrs. S. Charlesworth and Co., Richmond Hill Iron Works, Oldham. [*Charlesworth, Engineers, Oldham.* 63.]

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1895. Charnock, James (*Life Member*), Messrs. Vikoul Morosoff and Sons, Orehovo, near Moscow, Russia: (or care of Messrs. Samuel Montagu and Co., 60 Old Broad Street, London, E.C.)

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1890. Chater, John Richard, Messrs. Henry Pooley and Son, 28 Mosley Street, Newcastle-on-Tyne.

1885. Chatfeild Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1891. Chatterton, Alfred, Professor of Engineering, College of Engineering, Madras, India.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and High Lawn, Broad Oak Park, Worsley, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1897. Childe, Henry Slade, Messrs. Childe and Rowand, Wakefield. [*Childe, Wakefield.* 33.]

1895. Chittenden, Edmund Barrow, West Malling, Kent.

1880. Churchward, George Dundas, Locomotive Superintendent, Imperial Chinese Railways, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, 30 Boulevard des Italiens, Paris.)

1894. Churchward, George Jackson, Great Western Railway Carriage Works, Swindon.

1896. Claremont, Ernest Alexander, Messrs. F. H. Royce and Co., Cooke Street, Hulme, Manchester. [*Switch, Manchester.* 772.]

1891. Clark, Augustus, Bowman's Heirs, Pernambuco, Brazil.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1867. Clark, George, Southwick Engine Works, near Sunderland.

1896. Clark, George, Jun., Southwick Engine Works, near Sunderland.

1889. Clark, Thomas Alexander, Superintendent of Workshops, George Heriot's Hospital School, Edinburgh.

1896. Clark, Thomas Forster, Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1894. Clarkson, Charles, Green Lane, Chester Road, Erdington, Birmingham.

1891. Clarkson, Thomas, Clarkson and Capel Steam Car Syndicate, Deverell Street, London, S.E.

1892. Clay, Charles Butler, National Telephone Co., St. Andrew's House, Holborn Circus, London, E.C.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1890. Cleathero, Edward Thomas, The Hollies, Barrington Road, Altrincham.

1890. Cleaver, Arthur, Engineer, Nottingham Laundry Co., Sherwood, near Nottingham; and Hornby House, Sherwood, near Nottingham.

1890. Cleland, William, Sheffield Testing Works, Blonk Street, Sheffield.

1873. Clench, Frederick, Lincoln Works, Chesterfield.

1897. Clifford, Charles, Chief Mechanical Engineer, Great Northern Railway of Ireland, Dundalk.

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, Engineers' Department, London County Council, Spring Gardens, London, S.W.

1881. Cochrane, Brodie, Greencroft Park, Lanchester, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1864. Coddington, Sir William, Bart., M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1889. Coey, Robert, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1889. Colam, William Newby, 57 Henderson Row, Edinburgh. [*Colam, Cable, Edinburgh.*]

1892. Cole, Henry Aylwin Bevan, 79½ Gracechurch Street, London, E.C. [*Carbuncle, London.*]

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1894. Collis, Alfred Edward, Lincoln Science School, Monk's Road, Lincoln.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 14 Victoria Street, Westminster, S.W.

1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.

1889. Common, John Freeland Fergus, 4 Bute Crescent, Cardiff.

1881. Compton-Bracebridge, John Edward, Messrs. Easton Anderson and Goolden, Broad Sanctuary Chambers, Broad Sanctuary, Westminster, S.W.

1896. Conaty, George, Engineer, Birmingham and Midland Tramways, Birmingham.

1888. Constantine, Ezekiel Grayson, 17 St. Ann's Square, Manchester. [*Constant, Manchester.*]

1886. Conyers, Sidney Ward, Railway Construction Branch, Public Works Department, Sydney, New South Wales.

1874. Conyers, William, New Zealand Chambers, 483 Collins Street, Melbourne, Victoria.

1896. Cook, Charles, Messrs. Barry, Henry and Co., 64 Mark Lane, London, E.C.

1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helen's, Lancashire.

1892. Cooke, Rupert Thomas, 889 Ashton Old Road, Manchester.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, 6 Wardrobe Place, Doctors' Commons, London, E.C.

1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.

1891. Cooper, Myles, 36 Victoria Street, Manchester.

1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1892. Corin, Philip Burne, Messrs. J. M. B. Corin and Son, Anchor Foundry, Penzance.

1895. Corner, John Frederick, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1895. Cornish, Edwin, Staff Engineer, R.N., H.M.S. "Hawke," Mediterranean Station.

1848. Corry, Edward (*Life Member*), 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Karachi, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1883. Cotton, Henry Streatfeild, Oaklands, Isfield, near Uckfield.

1896. Cottrell, Stephen Butler, Pacific Buildings, 31 James Street, Liverpool. [*Motor, Liverpool.* 5460.]

1894. Cottrill, John Ormerod, Bee Hive Works, Bolton.

1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.

1895. Couper, Sinclair, Messrs. Lindsay Burnet and Co., Moore Park Boiler Works, Govan, Glasgow. [*Burnet, Glasgow.* 1513.]

1878. Courtney, Frank Stuart, Messrs. Easton Anderson and Goolden, Broad Sanctuary Chambers, Broad Sanctuary, Westminster, S.W.; and 39 Alleyn Park, Dulwich, London, S.E.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1896. Cowdell, Henry Charles, Cradley Boiler Works, Cradley Heath, S.O., Staffordshire. [*Boiler, Cradley Heath.*]

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1880. Cowper, Charles Edward, 144 Addison Gardens, London, W.

1892. Cowper-Coles, Sherard Osborn, 39 Victoria Street, Westminster, S.W. [*Zincking, London.*]

1888. Cox, Herbert Henry, 17 Wodehouse Terrace, Falmouth.

1897. Cox, Job, Birmingham Corporation Baths and Parks Departments, Kent Street, Birmingham. [994.]

1896. Craig, Alexander, Messrs. A. and G. Craig, Queen's Quay and Boating Club Road, Londonderry.

1866. Craven, William, Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1894. Craven, William H. S., Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1897. Crawford, Walter William, 91 Pitt Street, Sydney, New South Wales. [*Carbonic, Sydney.* 2362.]

1889. Cribb, Frederick James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1893. Crippin, Thomas Henry, Bolton Engineering Co., Turton Street, Bolton; and 89 Bury New Road, Bolton.

1897. Critchley, James Sidney, Works Manager, Daimler Motor Co., Motor Mills, Coventry.

1883. Croft, Henry, M.P., Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 14 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1891. Crosland, Joseph, Messrs. Seebohm and Dieckstahl, Dannemora Steel Works, Sheffield; and Stanley Avenue, Birkdale, Southport.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1889. Cullen, William Hart, Resident Engineer, The Aluminium Co., Oldbury, near Birmingham.

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.; and 4 Westcombe Park, Blackheath, London, S.E.

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India; and Cumbala Hill, Bombay, India.

1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]

1891. Daglish, Harry Bolton, Messrs. Robert Daglish and Co., St. Helen's Engine and Boiler Works, St. Helen's, Lancashire.

1895. Daintree, Thomas Ekins, 78 Leicester Road, Loughborough.

1883. D'Albert, Charles, Société des Anciens Établissements Hotchkiss et Cie., 6 Route de Gonesse, St. Denis, Seine, France.

1890. Dalby, William Ernest, Professor of Mechanical Engineering, City and Guilds of London Institute: Finsbury Technical College, Leonard Street, City Road, London, E.C.

1889. Dalgarno, James Robert, 454 Great Western Road, Aberdeen.

1893. Dall, John, Messrs. Harland and Wolff, Belfast.

1893. Dalrymple, Alexander, Superintendent Engineer, Hall Line of Steamers, 19 Tower Buildings N., Water Street, Liverpool.

1881. D'Alton, Patrick Walter, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Fern Bank, Horsforth, Leeds.

1891. Daniels, Thomas, Messrs. Nasmyth Wilson and Co., Patricroft, Manchester.

1888. Darbishire, James Edward, 110 Cannon Street, London, E.C. [*Ezra, London.* 11306.]

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W. [*Subterranean, London.*]

1890. Davidson, Albert, 139 Norfolk Street, Sheffield.

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1880. Davies, Charles Merson, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow; and Leslie House, Pollokshields, Glasgow.

1897. Davies, Edmund Joseph, Messrs. Ransomes, Sims and Jefferies, Orwell Works, Ipswich.

1885. Davies, Edward John Mines, 24 Harrington Square, London, N.W.

1891. Davies, John Hubert, P.O. Box 455, Johannesburg, Transvaal, South Africa.

1894. Davis, George, Engineer's Office, Lancashire and Yorkshire Railway, Hunt's Bank, Manchester.

1877. Davison, John Walter, Bombay Baroda and Central India Railway, Ahmedabad, India: (or care of Mrs. Channon, 97 Shirland Road, Maida Vale, London, W.)

1884. Davison, Robert, Locomotive Department, Caledonian Railway, St. Rollox, Glasgow.

1873. Davy, David, Broom Croft, Parkhead, Sheffield.

1892. Davy, William James, 15 Victoria Street, Westminster, S.W.

1874. Daw, Samuel, 50 Chelsea Road, Southsea, Portsmouth.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1875. Dawson, Edward, 2 Windsor Place, Cardiff. [*Mechanical, Cardiff.*]

1896. Day, Charles, Messrs. Cole, Marchent and Morley, Prospect Foundry, Bradford.

1890. Day, George Cameron, Messrs. Day Summers and Co., Northam Iron Works, Southampton.

1886. Dayson, William Ogden, Blaenavon Works, Blaenavon, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, 32 Victoria Street, Westminster, S.W.

1880. Deacon, Richard William, Glenthorne, Astwood, Worcester.

1894. Deakin, Benjamin Walter, Bournemouth and District Electric Supply Co., Verulam House, Yelverton Road, Bournemouth.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1887. Deas, James, Clyde Navigation, Glasgow.

1866. Death, Ephraim, Beresford House, Leicester.

1890. Deeley, Richard Mountford, Locomotive Department, Midland Railway, Derby; and 10 Charnwood Street, Derby.

1889. Defries, Wolf, Messrs. Defries and Sons, 147 Houndsditch, London, E. [*Defries, London.*]

1882. Denison, Samuel, Messrs. Samuel Denison and Son, Hunslet Foundry, Leeds. [*Weigh, Leeds.* 221.]

1892. Dennis, George D., 26 Newton Road, Bayswater, London, W.

1888. Dent, Charles Hastings, London and North Western Railway, Lime Street Station, Liverpool.

1895. Dewhurst, John Henry, Messrs. John Dewhurst and Son, Attercliffe Road, Sheffield. [1614.]

1883. Dick, Frank Wesley, Palmers Shipbuilding and Iron Works, Jarrow.

1891. Dick, John Norman, Government Marine Surveyor, Penang, Straits Settlements.

1890. Dickinson, Alfred, 120 Colmore Row, Birmingham. [*Traction, Birmingham.*]

1891. Dickinson, James Clark, Palmer's Hill Engine Works, Sunderland.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1892. Dickinson, Richard Henry, Locomotive Superintendent, Birmingham Central Tramways, Kyotts Lake Depôt, Birmingham.

1875. Dickinson, William, Warham Road, Croydon.

1886. Dixon, Robert, Oakfield, Lymm, Warrington.

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.* Nat. 330; Mutual 1330.]

1897. Dixon, Walter Frank, Chief Engineer, Locomotive Department, Sormovo Works, Nijni Novgorod, Russia.

1887. Dixon, William Basil, 18 Westcott Street, Hull.

1896. Dobson, Adam, 7 Marsh's Buildings, Donegall Street, Belfast. [966.]

1872. Dobson, Sir Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, De Volharding, Soerabaya, Java: (or care of Miss Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1889. Dolby, Ernest Richard, 8 Prince's Street, Westminster, S.W.

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan (*Life Member*), Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E. [*Donkin Company, London.* 4662.]; and The Mount, Wray Park, Reigate.

1895. Donkin, Harry Julyan, Works Manager, Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E.

1891. Donovan, Edward Wynne, Messrs. J. S. Leach and Co., Broughton Bridge Iron Works, Salford, Manchester. [*Dazzle, Manchester.*]

1896. Dorman, William Sansom, Works Manager, Gloucester Wagon Works, Gloucester.

1865. Douglas, Charles Prattman (*Life Member*), Thornbeck Hill, Carmel Road, Darlington.

1879. Douglass, Sir James Nicholas, F.R.S., Stella House, Bonchurch, Ventnor.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1891. Douglass, William James, Messrs. Douglass Brothers, Globe Iron Works, Blaydon-on-Tyne, R.S.O., County Durham.

1887. Douglass, William Tregarthen, 15 Victoria Street, Westminster, S.W.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hodroyd Hall, near Barnsley.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Belle Vue, Marton Road, Middlesbrough.

1881. Dowson, Joseph Emerson, 39 Old Queen Street, Westminster, S.W. [*Gaseous, London.*]

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1890. Drewet, Tom, Government Senior Inspector of Steam Boilers, Town Custom House, Bombay, India.

1896. Dronsfield, William, Messrs. Dronsfield Brothers, Atlas Works, Oldham.

1886. Drummond, Dugald, Locomotive Engineer, London and South Western Railway, Nine Elms, London, S.W.

1889. Drummond, Richard Oliver Gardner, P. O. Box 92, Johannesburg, Transvaal, South Africa.

1896. Dryden, Thomas, Grimshaw Street Foundry, Preston. [36.]

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1879. Duncan, David John Russell, 28 Victoria Street, Westminster, S.W.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1894. Dunell, George Robert, 36 Bedford Street, Strand, London, W.C.; and 7 Spencer Road, Grove Park, Chiswick, London, W.

1892. Dunlop, James, Victoria Jubilee Technical Institute, Byculla, Bombay, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1890. Dunn, Hugh Shaw, Engineer, Caprington Collieries, Kilmarnock.

1895. Dunn, Matthew, Manager, Gas Works, Selby.

1886. Duvall, Charles Anthony, Messrs. Ashwell and Nesbit, Victoria Foundry, Sycamore Lane, Leicester.

1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward. Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1892. Eastwood, Thomas Carline, Messrs. Eastwood Swingler and Co., Victoria and Railway Iron Works, Derby. [*Swingler, Derby.*]

1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.

1896. Eborall, Cornelius Willes, District Locomotive Superintendent, East Indian Railway, Jamalpur, India: (or care of Messrs. William Watson and Co., 7 Waterloo Place, Pall Mall, London, S.W.)

1878. Eckart, William Roberts, Room 4, Nevada Block, San Francisco; and 3014 Clay Street, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1893. Eden, The Hon. Francis Fleetwood, Los Talleres de Sola, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1887. Edlin, Herbert William, P.O. Box 674, Johannesburg, Transvaal, South Africa. [*Motor, Johannesburg.*]

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1885. Edwards, Walter Cleeve, Public Works Department, Vryburg, British Bechuanaland, South Africa.

1896. Ekin, Tom Charles, 21 Old Queen Street, Westminster, S.W.

1888. Ellery, Henry George, 7 Fernbank Road, Redland, Bristol.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1892. Elliott, Archibald Campbell, D.Sc., Professor of Engineering, University College of South Wales and Monmouthshire, Cardiff.

1895. Elliott, George, 10 Oceanic Avenue, Belfast.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1895. Ellis, Arthur Devonshire, Managing Director, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford.

1880. Ellis, Oswald William, 31 Grosvenor Place, Jesmond, Newcastle-on-Tyne. [*Robey, Newcastle-on-Tyne.*]

1896. Ellis, William Frederick Wood, 2 Dulal Street, Fort, Bombay, India; and 23 Waldemar Avenue, Fulham, London, S.W.

1897. Elsworth, John Francis, Les Huileries, Alexandria, Egypt.

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India; and Altamont Road, Cumbala Hill, Bombay, India.

1878. Elwin, Charles, London County Council, Spring Gardens, London, S.W.

1890. English, Lt.-Colonel Thomas, Hawley, near Dartford.

1894. English, Thomas Matthew, Superintendent, Die and Coining Department, H. M. Mint, Bombay, India.

1894. Ennor, Charles John, 55 Rua da Reboleira, Oporto, Portugal.

1890. Esson, John, Chatteris Engineering Works, Chatteris, S.O., Cambridgeshire.

1889. Etches, Harry, 17 Napoleon Street, Brantford, Ontario, Canada.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Messrs. Bolckow Vaughan and Co., Cleveland Iron and Steel Works, South Bank, R.S.O., Yorkshire.

1892. Evanson, Frederic Macdonnell, Hazelhurst, Urmston, near Manchester.

1887. Everard, John Breedon, 6 Millstone Lane, Leicester.

1887. Everitt, Nevill Henry, Messrs. Thomas Piggott and Co., Atlas Works, Birmingham; and Hillside, Knowle, Warwickshire.

1897. Evers, Joseph Henry, General Manager, Messrs. Manning, Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1894. Ewen, John Taylor, 4 Ann Street, Hillhead, Glasgow.

1881. Ewen, Thomas Buttwell, Messrs. Ewen and Mitton, Smithfield Works, Sherlock Street, Birmingham.

1891. Ewing, James Alfred, F.R.S., Professor of Mechanism and Applied Mechanics, Engineering Department, The University, Cambridge; and Langdale Lodge, Cambridge.

1890. Exton, George Gaskell, Messrs. Chubb and Son, 128 Queen Victoria Street, London, E.C.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and care of Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1882. Feeny, Victor Isidore, 60 Queen Victoria Street, London, E.C. [*Victor Feeny, London.*]

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1869. Fenwick, Clennell, 57 Gracechurch Street, London, E.C.

1892. Fenwick, James, 19 Bridge Street, Sydney, New South Wales. [1038.]

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1896. Ferguson, William Deeble, Albert Villa, Ravenhill Road, Belfast.

1866. Fiddes, Walter, 2 Queen's Avenue, Tyndall's Park, Bristol.

1867. Field, Edward, 4 Trafalgar Square, London, W.C.

1888. Field, Howard, 12 London Street, Fenchurch Street, London, E.C.

1884. Fielden, Joseph Petrie, Park Terrace, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1891. Finlayson, Finlay, Clydesdale House, Mossend, Lanarkshire.

1888. Fischer, Gustave Joseph, Railway Construction Branch, Public Works Department, Sydney, New South Wales; and Oakhurst, West Street, North Sydney, New South Wales.

1897. Fish, Sylvester Robert, Messrs. F. Street and Co., Palacio da Flôr da Murta, 156 Rua do Poço dos Negros 158, Lisbon, Portugal.

1889. Fisher, Henry Bedwell, Marine Shops, London Brighton and South Coast Railway, Newhaven, Sussex.

1884. Fisher, Henry Oakden, Ty Mynydd, Radyr, near Cardiff.

1897. Fisher, Pearson, Messrs. Edward Chester and Co., 120 Bishopsgate Street Within, London, E.C.

1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.

1877. Flannery, James Fortescue, M.P., 9 Fenchurch Street, London, E.C. [2283.]

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users', Manchester.*]

1892. Focken, Charles Frederick, care of Institute of Engineers and Shipbuilders, Hong Kong, China.

1859. Fogg, Robert, 159 Knight's Hill, West Norwood, London, S.E.

1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Bombay.

1892. Forbes, Percy Alexander, Messrs. Lambert Brothers, Tube Mills, Iron and Brass Works, Walsall.

1882. Forbes, William George Loudon Stuart, Mechanical Superintendent, H. M. Mint, Calcutta.

1892. Forrest, Hilary Sheldon, General Manager, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.

1882. Forsyth, Robert Alexander, Courtway, Gold Tops, Newport, Monmouthshire.

1889. Foster, Ernest Howard, Messrs. Henry R. Worthington, 86 Liberty Street, New York, United States.

1889. Foster, Herbert Anderton (*Life Member*), Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1888. Foster, James, Lily Bank, St. Andrew's Drive, Pollokshields, Glasgow.

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Consulting Engineer, Dock Office, West Hartlepool; and 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Manager, Glasgow Corporation Gas Department, City Chambers, 45 John Street, Glasgow.

1885. Fourny, Hector Foster, French Chambers, Queen's Dock-Side, Hull. [*Veritas, Hull.*]

1866. Fowler, George, Basford Hall, near Nottingham.

1896. Fowler, Henry, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1847. Fowler, Sir John, Bart., K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1894. Fowler, Robert Henry, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Fowler, Leeds.*]

1885. Fowler, William Henry, Hodson's Court, Corporation Street, Manchester; and Brook House, Flixton, near Manchester.

1866. Fox, Sir Douglas, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Blairquhan Castle, Maybole.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Goldsbrough Mort and Co., 149 Leadenhall Street, London, E.C.)

1877. **Fraser, John Hazell,** Messrs. John Fraser and Son, Millwall Boiler Works, London, E.; and 110 Cannon Street, London, E.C.

1888. **Frenzel, Arthur Benjamin,** 314 W. 133rd Street, New York, United States.

1891. **Frier, John Drummond,** 186 Plumstead Common Road, Plumstead.

1866. **Fry, Albert,** Bristol Wagon Works, Lawrence Hill, Bristol.

1891. **Fuller, Charles Frederick,** 171 Queen Victoria Street, London, E.C.

1884. **Furness, Edward,** Knollcroft, Knoll Road, Bexley, S.O., Kent.

1890. **Gadd, William,** Assistant Locomotive Engineer, Waterford and Limerick Railway, Limerick.

1866. **Galloway, Charles John,** Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. **Galton, Sir Douglas,** K.C.B., D.C.L., LL.D., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1884. **Ganga Ram, Rai Bahadur,** Executive Engineer, Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Thomas Wilson and Co., 24 Rood Lane, London, E.C.)

1891. **Garrard, Charles Riley,** Garrard Manufacturing Co., Magneto Works, Ryland Street, Birmingham. [*Gearing, Birmingham.* 904.]

1882. **Garrett, Frank,** Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1894. **Gatehouse, Tom Ernest,** 4 Ludgate Hill, London, E.C. [*Ageekay, London.* Holborn, 933.]

1867. **Gauntlett, William Henry,** 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1895. **Gaynor, Captain Henry Francis,** R.E., School of Military Engineering, Chatham.

1888. **Gaze, Edward Henry James,** 4 Victoria Drive, Mount Florida, Glasgow.

1895. **Geach, Frederick Samuel,** Messrs. John Vipond and Co., Varteg Hill Colliery, near Pontypool.

1888. **Geddes, Christopher,** 2A Drury Buildings, Water Street, Liverpool. [*Graccius, Liverpool.*]

1880. **Geoghegan, Samuel,** Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]

1896. **German, Walter Hussey,** Colonial Sugar Refining Co., Sydney, New South Wales.

1887. **Gibb, Andrew,** Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.; and 30 South Street, Greenwich, London, S.E.

1871. **Gibbins, Richard Cadbury,** Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1883. Gilchrist, Percy Carlyle, F.R.S. (*Life Member*), Frognal Bank, Finchley New Road, Hampstead, London, N.W.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1889. Gill, Frederick Henry, Messrs. Alexander Penney and Co., 107 Fenchurch Street, London, E.C.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1881. Girdwood, William Wallace, 24 Plashet Road, Upton Manor, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1896. Glasgow, Arthur Graham, Messrs. Humphreys and Glasgow, 9 Victoria Street, Westminster, S.W.

1887. Gledhill, Manassah, Sir W. G. Armstrong, Whitworth and Co., Openshaw, Manchester.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.

1882. Goldsmith, Alfred Joseph, Lillington, Moray Street, New Farm, Brisbane, Queensland.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1890. Goodman, John, Professor of Engineering, Yorkshire College, Leeds.

1889. Goold, William Tom, Shillingford Works, Wallingford.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 143 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1878. Grafton, Alexander, Vulcan Works, Bedford. [*Grafton, Bedford.*]

1894. Graham, Maurice, Cawder House, Poplar Avenue, Edgbaston, Birmingham.

1896. Graham, Robert, Ponce, Porto Rico.

1886. Grant, Percy, Assistant Locomotive, Carriage, and Wagon Superintendent, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or care of John M. Grant, 136 Sutherland Avenue, Maida Vale, London, W.)

1895. Grant, Thomas Maxwell, Managing Director, Messrs. Napier Brothers, 100 Hyde Park Street, Glasgow. [*Windlass, Glasgow.* 714.]

1891. Gray, George Macfarlane (*Life Member*), Board of Trade Surveyors' Office, Custom House Arcade, Liverpool.

1865. Gray, John Macfarlane, 4 Ladbroke Crescent, Notting Hill, London, W.

1879. Gray, Thomas Lowe, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and 24 St. Michael's Road, Stockwell, London, S.W.

1861. Green, Sir Edward, Bart., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1888. Green, Henry Joseph Kersting, 29 Clive Street, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1893. Green, William Penrose, Messrs. Thomas Green and Son, Smithfield Iron Works, Leeds.

1895. Greensmith, James Eades, Mason Machine Works, Taunton, Massachusetts, United States.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry (*Life Member*), Birmingham Metal and Munitions Co., Adderley Park Mills, Birmingham.

1894. Gregory, Horace Mark, Messrs. Brown, Lenox and Co., 9 Martin's Lane, Cannon Street, London, E.C.; and Ynysyngharad, Pontypridd.

1892. Gresham, Harry Edward, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1883. Grew, Frederick, 63 Burnt Ash Hill, Lee, London, S.E.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1895. Griffith, Percy, 55 Parliament Street, Westminster, S.W.

1895. Griffiths, Harry Denis, P.O. Box 311, Auckland, New Zealand.

1884. Griffiths, James E., Messrs. Griffiths and James, 2 Bute Crescent, Cardiff.

1873. Griffiths, John Alfred, Peel Street, South Brisbane, Queensland: (or care of Thomas Griffiths, Langham Road, Bowdon, near Altrincham.)

1889. Grimshaw, James Walter, Resident Engineer, Harbours and Rivers Department, Sydney, New South Wales; and Australian Club, Sydney, New South Wales.

1891. Groom, Richard Alfred, Shropshire Works, Wellington, Salop.

1879. Grose, Arthur, Messrs. Grose Norman and Co., Reliance Works, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1870. Gwynne, James Eglinton Anderson (*Life Member*), Brooke Street Works, Holborn, London, E.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.; and 89 Cannon Street, London, E.C.

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield. [*Hadfield, Sheffield.*]

1894. Haigh, Noel Newall, Messrs. W. B. Haigh and Co., Globe Iron Works, Plane Street, Oldham.

1897. Haldane, John Wilton Cuninghame, 30 North John Street, Liverpool.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., Third Street, East Cambridge, Massachusetts; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1892. Hall, George Edward, Mechanical Superintendent, Lighting Department, Salford Corporation, Wilburn Street, Salford, Manchester.

1894. Hall, Henry Platt, Messrs. Platt Brothers and Co., Hartford New Works, Oldham.

1881. Hall, John Percy, Carville, Lawrie Park Road, Sydenham, London, S.E.

1882. Hall, John Willim, Ivy House, Bilston.

1890. Hall, Oscar Standring, Messrs. Robert Hall and Sons, Hope Foundry, Bury, Lancashire.

1874. Hall, Thomas Bernard, 119 Colmore Row, Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham. [*Tamar, Birmingham.*]

1871. Hall, William Silver, 9A Tsukiji, Tokyo, Japan: (or care of Messrs. Takata and Co., 88 Bishopsgate Street Within, London, E.C.) [*Silverhall, Tokyo.*]

1889. Hall-Brown, Ebenezer, Messrs. Hall-Brown Buttery and Co., Helen Street Engine Works, Govan, Glasgow. [*Triple, Glasgow.* 1843.]

1880. Hallett, John Harry, 123 Bute Street, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* 3075, care of Victoria Chambers Co.]

1895. Halstead, John Henry, Fremantle, Western Australia; and 24 Alma Road, Birkdale, Southport.

1894. Hamer, Walter, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1894. Hamilton, Robert, Park Villa, Institution Hill, Singapore, Straits Settlements.

1875. Hammond, Walter John, The Grange, Knockholt, near Sevenoaks.

1886. Hanbury, John James, Edgeley, Walm Lane, Willesden Park, London, N.W.

1896. Handyside, Charles Baird, Messrs. Waterlow and Sons, Finsbury, London, E.C.

1892. Hansell, Robert Blackwell, Tenth Street, Walbrook, Baltimore, Maryland, United States: (or care of James Hansell, 62 Jerningham Road, New Cross, London, S.E.)

1891. Harcourt, Otto Simon Henry, Clarence Iron Works, Leeds.

1894. Harding, James Cooper, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Harding, Thomas Walter, Tower Works, Leeds.

1874. Harding, William Bishop, 18 St. James' Square, London, S.W.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.

1869. Harfield, William Horatio, Arundel House, Thames Embankment, London, W.C. [*Harfield, London.*]

1887. Hargraves, Richard, 4 Richmond Terrace, Blackburn.

1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1888. Harker, William, Messrs. Richard Schram and Co., Cannon Street House, London, E.C. [*Schram, London.*]

1894. Harmer, Oscar, Messrs. Alfred Herbert and Co., Coventry; and Hopedale, Spencer Park, Coventry.

1891. Harris, Gordon, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.

1879. Harris, Henry Graham, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1888. Harrison, George, 35 Therapia Road, Honor Oak, London, S.E.

1889. Harrison, Captain Gilbert Harwood, R.E., War Office, Whitehall, London, S.W.

1885. Harrison, Joseph, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Harrison, Joseph Hutchinson, Messrs. Howson and Harrison, 2 Exchange Place, Middlesbrough; and Clifford Villa, Coatham, Redcar.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 78 Queen Victoria Street, London, E.C.

1894. Harrison, William John, Locomotive Superintendent, Cia. Paulista, Rio Claro, São Paulo, Brazil; and 44 Bournemouth Road, Folkestone.

1890. Harrison, William Robert, 4 Parliament Street, Hull. [*Arbitrate, Hull.*]

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1892. Harvey, Francis Haniel, Messrs. Harvey and Co., Hayle Foundry, Hayle, Cornwall.

1886. Harvey, John Boyd, North's Navigation Collieries, Tondû, near Bridgend, Glamorganshire.

1883. Harvey, Robert, 1 Palace Gate, London, W.

1897. Harvey, Robert, Managing Director, Messrs. McOnie, Harvey and Co., Scotland Street Engine Works, Glasgow. [*Maconie, Glasgow.* 565.]

1878. Harwood, Robert, Soho Iron Works, Bolton.

1881. Haslam, Sir Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 6 Lombard Court, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, Constitutional Club, Northumberland Avenue, London, W.C.

1892 Hawkins, Rupert Skelton, District Locomotive Superintendent, Indian Midland Railway, Jhansi, India.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1891. Hawksley, George William, Brightside Boiler and Engine Works, Savile Street East, Sheffield. [*Hawksley, Sheffield.* 337.]

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, 55 Steep Hill, Lincoln.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1885. Head, Archibald Potter, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London.* 3237]; and Queen's Square, Middlesbrough.

1888. Head, Harold Ellershaw, 5 Ilchester Mansions, Kensington, London, W.

1869. Head, Jeremiah, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London.* 3237.]; and Queen's Square, Middlesbrough. (Former Member 1859–1861.)

1857. Healey, Edward Charles, 33 Norfolk Street, Strand, London, W.C.

1890. Heap, Ray Douglas Theodore, Mortimer House, 23 Granville Place, Portman Square, London, W.; and The Firs, Tyler's Green, Penn, Amersham.

1872. Heap, William, 28 Chapel Street, Liverpool. [*Metal, Liverpool.* 809.]

1889. Heath, George Wilson, Messrs. Heath and Co., Observatory Works, Crayford, Kent.

1888. Heatly, Harry, Messrs. Heatly and Gresham, 110 Cannon Street, London, E.C.; and Ballygunge, West Hill Road, Wandsworth, London, S.W.

1897. Heaton, Charles, Brades Steel Works, near Birmingham. [*Brades, Birmingham.*]

1897. Heaton, George, Brades Steel Works, near Birmingham. [*Brades, Birmingham.*] (Former Member 1860–1869.)

1875. Heenan, Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester; and The Manor House, Wilmslow, near Manchester. [*Spherical, Newton Heath.*]

1895. Heinke, Edwin Harry Alfred, Locomotive Superintendent, La Guaira and Caracas Railway, Caracas, Venezuela: (or care of Miss F. Heinke, The College, Stoke Bishop, near Bristol.)

1879. Hele-Shaw, Henry Selby, LL.D., Professor of Engineering, University College, Liverpool.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1888. Henning, Gustavus Charles, 548 W. 149th Street, New York, United States.

1879. Henriques, Cecil Quixam, Messrs. John H. Wilson and Co., 15 Victoria Street, Westminster, S.W. [*Drague, London.*]

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1891. Hepburn, Thomas, Officiating Chief Mechanical Engineer, Small Arms Ammunition Factory, Kirkee, Poona, India.

1892. Herbert, Alfred, Machine-Tool Works, Coventry. [*Lathe, Coventry.* 52.]

1893. Herbert, Charles, 35 Queen Victoria Street, London, E.C. [*Mancunian, London.*]

1893. Herbert, George Henry, Messrs. Richard Hornsby and Sons, 75A Queen Victoria Street, London, E.C.

1894. Herman, Benjamin Richard, Messrs. B. R. Herman and Co., McLeod Road, Karachi, India. [*Herman, Karachi.* 47.]

1884. Hernu, Arthur Henry, 69 Victoria Street, Westminster, S.W.

1894. Herriot, William Scott, 187 Osmaston Road, Derby.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1897. Hetherington, Edward Palmer, Messrs. William Muir and Co., Britannia Works, Sherbourne Street, Strangeways, Manchester.

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1885. Hicken, Thomas, La Compañia Fabricantes Ingleses, 302 Calle Balcarce, Buenos Aires, Argentine Republic: (or care of Miss Hicken, Bourton, near Rugby.)

1896. Higby, Robert George, Sitarampur, Bengal, India.

1894. Higginbottom, Lloyd, Messrs. Higginbottom and Mannock, Crown Iron Works, West Gorton, Manchester.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1890. Hiller, Edward George, Chief Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1882. Hiller, Henry, Consulting Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester; and Athelney, Stanley Road, Alexandra Park, Manchester.

1873. Hilton, Franklin, 45 Talbot Street, Southport.

1897. Hiraoka, Hiroshi, Hiraoka Engineering Works, Honjo, Tokyo, Japan. [*Herocar, Tokyo.*]

1897. Hirst, James, Chief Engineer, Mount Morgan Gold Mining Co., Mount Morgan, Queensland.

1896. Hitchcock, Cyril, District Locomotive Superintendent, North Western Railway, Lahore, Punjaub, India.

1891. Hodge, Arthur, Belle Vue Terrace, St. Austell.

1891. Hodges, Frank Grattidge, Locomotive Department, Midland Railway, Burton-on-Trent.

1896. Hodges, Marcus Henry, Messrs. Hodges Brothers, City Basin Iron Works, Exeter.

1870. Hodges, Petronius, 101 Burngreave Road, Pitsmoor, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]

1889. Hodgson, George Herbert, Thornton Road, Bradford.

1892. Hodgson, Henry Edwin, Brookhouse Iron Works, Cleckheaton, S.O., Yorkshire.

1891. Hogarth, Thomas Oswald, Great Western Railway Works, Swindon.

1889. Hoggins, Alfred Farquharson, Brush Electrical Engineering Co., 49 Queen Victoria Street, London, E.C.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1895. Holgate, Charles Henzell, School Close Works. Leeds.

1884. Holland, Calvert Bernard, Hazel Villa, Thicket Road, Anerley, London, S.E.

1895. Holliday, John, Messrs. A. Guinness, Son and Co., St. James' Gate Brewery, Dublin.

1886. Hollis, Charles William, Nottingham Engineering Co., St. Alban's Works, Radford, Nottingham. [*Iron, Nottingham.* 1578.]

1885. Hollis, Henry William, Whitworth House, Spennymoor.

1896. Holman, Frederick, Messrs. N. Holman and Sons, Penzance Foundry, Penzance.

1891. Holman, Hugh Wilson, Messrs. E. J. Caiger and Co., 92 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1896. Holmes, Percy Frederick, Messrs. W. C. Holmes and Co., Whitestone Iron Works and Turnbridge Foundries, Huddersfield. [*Holmes, Huddersfield.* 113.]

1892. Holmström, Carl Albert, care of Swedish and Norwegian Consulate. Shanghai, China: (or care of Messrs. Vickers Sons and Maxim, 28 Victoria Street, Westminster, S.W.)

1883. Holroyd, John, 13 Alleyn Terrace, Park Road, West Dulwich, London, S.E.

1873. Holt, Henry Percy, 22 Chancery Lane, London, W.C.

1890. Holt, Robert, 2 Paper Buildings, The Temple, London, E.C.

1888. Homan, Harold, Messrs. Homan and Rodgers, 10 Marsden Street, Manchester. [*Namoh, Manchester.* 637.]

1895. Homfray, Samuel George, Sir W. G. Armstrong, Whitworth and Co., 8 Great George Street, Westminster, S.W.

1890. Hooker, Benjamin, Pear Tree Court, Farringdon Road. London, E.C.

1892. Hope, John Basil, Locomotive Department, North Eastern Railway, Leeds.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1894. Hopkinson, Edward, D.Sc., Messrs. Mather and Platt, Salford Iron Works, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., 26 Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1890. Hopper, Allan, Messrs. William Hopper and Co., Moscow, Russia.

1890. Hopper, James Russell, Messrs. William Hopper and Co., Moscow, Russia.

1889. Hopwood, John, Locomotive Superintendent, Argentine Great Western Railway, Mendoza, Argentine Republic.

1895. Horner, John, Clonard Foundry, Belfast.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1889. Horsfield, Cooper, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1891. Horsfield, Ralph, Messrs. Ralph Horsfield and Co., Chapel-en-le-Frith, near Stockport.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1892. Horsnell, Daniel, 79 Farringdon Road, London, E.C.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1886. Hosgood, John Howell, Locomotive and Hydraulic Superintendent, Barry Dock and Railways, Barry, near Cardiff.

1891. Hosgood, Walter James, Locomotive Department, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Richard, care of Messrs. W. Hosken and Co., P.O. Box 667, Johannesburg, Transvaal, South Africa: (or care of J. Hosken, 27 Mincing Lane, London, E.C.)

1892. Houghton, Francis Gassiot, 23 Tooting Bec Road, Tooting, London, S.W.

1866. Houghton, John Campbell Arthur, Sparnon, Torquay.

1889. Houghton, Thomas Harry, 58 Pitt Street, Sydney, New South Wales: (or care of Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.) [*Expansion, Sydney.*]

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1896. House, Henry Alonzo, Bridgeport, Connecticut, United States.

1891. How, William Field, Mutual Life Buildings, George Street, Sydney, New South Wales. [*Alaska, Sydney.*]

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 90 Whitecross Street, London, E.C.

1897. Howard, Henry Fox, Messrs. Hayward, Tyler and Co., 90 Whitecross Street, London, E.C.

1879. Howard, James Harold, Britannia Iron Works, Bedford; and The Grange, Kempston, Bedford.

1882. Howard, John William, Gloucester Wagon Works, Gloucester.

1896. Howarth, Alfred Montgomery, Railway Construction Department, Public Works Office, Sydney, New South Wales.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield [*Howell, Sheffield.*]; and The Tower, Hathersage, near Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1892. Howitt, James John, Messrs. Bowman Thompson and Co., Lostock Gralam, Northwich.

1882. Howl, Edmund, Messrs. Lee Howl and Co, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1891. Hoy, Henry Albert, Locomotive Works, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1891. Hubback, Charles Arbuthnot, Locomotive and Rolling Stock Superintendent, Natal and Nova Cruz Brazilian Railway, Natal, Rio Grande do Norte, Brazil.

1882. Hudson, John George, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton; and Glenholme, Bromley Cross, Bolton.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1893. Hudson, William, Ahmedabad, Bombay, India.

1881. Hughes, Edward William Mackenzie, Managing Director, Hughes' Solid Rolled Axle-Box Co., 53 Victoria Street, Westminster, S.W.; and 16 Court Road, West Norwood, London, S.E. [*Sirhind, London.*]

1867. Hughes, George Douglas, Leen Side Works, Nottingham.

1889. Hughes, John, Messrs. Hughes and Lancaster, 47 Victoria Street, Westminster, S.W.

1891. Hughes, Robert M., Bengal-Nagpur Railway, Chakardharpur, India: (or care of Reginald D. Hughes, 69 Cromford Road, West Hill, London, S.W.)

1892. Hullah, Arthur, Victoria Jubilee Technical Institute, Byculla, Bombay, India: (or care of Walter Hunter, 12 Chetwynd Terrace, Meadow Road, Leeds.)

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester.

1897. Hulse, Richard Lamplough, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.* 1427.]

1864. Hulse, William Wilson, Ordsal Works, Regent Bridge, Salford, Manchester.

1890. Humphries, Edward Thomas, Wyre, Pershore.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1894. Humpidge, James Dickerson, Messrs. Humpidge, Holborow and Co., Dudbridge Iron Works, Stroud, Gloucestershire [*Humpidge, Cainscross.*]; and Glengar, Frome Park Road, Stroud, Gloucestershire.

1889. Hunter, Charles Lafayette, Engineer, Bute Docks, Cardiff.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, 17 Victoria Street, Westminster, S.W. [*Westminster*, 75.]

1888. Huxley, George, 20 Mount Street, Manchester.

1885. Hyland, John Frank, Railway Contractor, São Carlos do Pinhal, Estado de São Paulo, Brazil: (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1897. I'Anson, Joseph Coventry, 31 Broadway, Westminster, S.W.

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, Mawson Chambers, 28 Deansgate, Manchester. [*Vacuum, Manchester.* 3857.]

1888. Ingleby, Joseph, 20 Mount Street, Manchester.

1883. Instone, Thomas, 146 Leadenhall House, Leadenhall Street, London, E.C.

1894. Iorns, Charles Risbec, Waverley Works, 22½ Cazenove Road, Stoke Newington, London, N.

1892. Irons, Thomas, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, New South Wales.

1894. Irwin, Thomas F., Messrs. Irwin, Atkinson and Young, 2A Tower Chambers, Old Church Yard, Liverpool. [*Irwall, Liverpool.* 2399.]

1895. Isaac, Robert, Messrs. Owen, Isaac and Owen, Union Iron Works, Portmadoc. [*Isaac, Portmadoc.*]

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Northern Railway, Doncaster.

1887. Ivatts, Lionel Edward, Hapetenea, Behobie, Basses-Pyrénées, France.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and Woodgreen, Wednesbury.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1895. Jackson, Robert Cattley, Newcastle-on-Tyne Electric Supply Co., Pandon Dene, Newcastle-on-Tyne. [*Supply, Newcastle-on-Tyne.* 530.]

1886. Jackson, Thomas, Woodlands View, Horsforth, near Leeds.

1889. Jackson, William, Thorn Grove, Mannofield, Aberdeen.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1893. James, Arthur William, Calcutta Landing and Shipping Co., 24 Strand Road, Calcutta, India.

1889. James, Charles William, Gwynant, Avington Grove, Penge, London, S.E.

1895. James, Christopher William, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1895. James, Enoch, General Manager, Patent Shaft and Axletree Works, Wednesbury.

1889. James, Reginald William, 1 Queen Victoria Street, London, E.C.

1879. Jameson, George, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1881. Jameson, John, Messrs. Jameson and Schaeffer, 2 Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1888. Jaques, Captain William Henry, 11 Broadway, New York, United States.

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1877. Jeffreys, Edward Homer, Hawkhills, Chapel Allerton, Leeds.

1893. Jenkin, Charles Frewen, Messrs. Nettlefolds, Castle Works, Tydu, near Newport, Monmouthshire.

1894. Jenkin, Thomas Henry, Messrs. J. Jamieson and Co., Queen's Dock Chambers, Hull. [*Propeller, Hull.* 94.]

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Jenkins, William John, Messrs. W. J. Jenkins and Co., Beehive Works, Retford.

1896. Jenkinson, Thomas, Messrs. Pilkington Brothers, Plate Glass Works, St. Helen's, Lancashire.

1893. Jennins, Henry Horwood, Messrs. Edwin Oldroyd and Co., Crown Works, Leeds. [*Calorifics, Leeds.* 241.]

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1889. Jessop, George, Messrs. Jessop and Appleby Brothers, London Steam-Crane and Engine Works, Leicester. [*Jessop, Leicester.*]

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury

1890. Johnson, John William, care of Baron L. Knoop, Maison de la Banque des Marchands, Ilyinka, Moscow, Russia.

1891. Johnson, Lacey Robert, Master Mechanic, Pacific Division, Canadian Pacific Railway, Vancouver, British Columbia.

1888. Johnson, Lawrence Potter, Insein, Lower Burma: (or 9 Blackheath Rise, Lewisham, London, S.E.)

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale; and Glebelands, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.; and The Warren Hill, Loughton, Essex.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1896. Johnston, James, Chief Engineer, Brighton Corporation Water Works, 12 Bond Street, Brighton. [140.]

1895. Johnstone, Captain James Henry L'Estrange, R.E. (*Life Member*), Horse Guards, Whitehall, London, S.W.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1891. Jones, Charles Frederick, 85 Davenport Street, Bolton.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Broomfield House, Perry Barr, Birmingham.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, District Locomotive Superintendent, North Western Railway, Rawal Pindi, Punjaub, India: (or care of Mrs. Edward Jones, Homelea, All Saints' Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, District Locomotive Superintendent, Midland Railway, Manchester.

1890. Jones, Morlais Glasfryn, 6 Delahay Street, Westminster, S.W.

1882. Jones, Samuel Gilbert, Hatherley Court, Gloucester.

1887. Jones, Thomas, Central Board School, Deansgate, Manchester; and 4 Manley Road, Alexandra Park, Manchester.

1872. Jones, William Richard Sumption, Whitehall Court, London, S.W.

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1891. Jordan, Henry George, Jun., Municipal Technical School, Princess Street, Manchester.

1880. Joy, David, 85 Gracechurch Street, London, E.C.; and 118 Broadhurst Gardens, West Hampstead, London, N.W. (Former Member 1853–1867.)

1891. Judd, Joseph Henry, School Board Offices, Manchester.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 65003.]

1889. Kanthack, Ralph, 18 Berners Street, London, W.

1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.

1869. Keen, Arthur, London Works, near Birmingham. [*Globe, Birmingham.*]

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Westbromwich.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Darlington.

1879. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 17 Victoria Street, Westminster, S.W. [*Kinematic, London.*]

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1892. Kennedy, Thomas, The Glenfield Engineering Works, Kilmarnock.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1892. Kensington, Frederick, 2 Copthall Buildings, London, E.C.

1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1890. Key, George Andrew, 27 Kirk Wynd, Kirkcaldy.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic: (or care of J. R. H. Keyworth, 28 Grosvenor Road, Birkenhead.)

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1894. Kiernan, George, Manager, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1895. King, Charles Penrose, Resident Engineer, Epsom Water Works, Epsom.

1897. King, Henry Charles, Great Western Railway Works, Swindon.

1895. King, Thomas Scott, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1893. Kinghorn, John Warden, care of Messrs. Jardine Matheson and Co., Hong Kong, China.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 101 Leadenhall Street, London, E.C. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Commissioner of Customs, Kowloon, Hong Kong, China: (or Grange Park, Prestwick, Ayrshire.)

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., M.P., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, 50 Southbrook Road, Lee, London, S.E.

1889. Knap, Conrad, 11 Queen Victoria Street, London, E.C.

1891. Knight, Bertrand Thornton, Royal Railway Department, Bangkok, Siam: (or care of Major Knight, Swansea.)

1886. Knight, Charles Albert, Babcock and Wilcox Co., 21 Bothwell Street, Glasgow.

1890. Knight, James Percy, Kaiser Steam Tug Co., 27 Great Tower Street, London, E.C. [*Longboat, London.* 11,203.]

1896. Kwang, Kwong Yung, Linsi Colliery; care of the Chinese Engineering and Mining Co., Tientsin, North China.

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead. [*Laird, Birkenhead.* 4003.]

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1897. Lambert, William Fraser, Messrs. G. S. Goodwin and Co., 19 James Street, Liverpool.

1896. Lane, Francis Lawrence, Works Manager, Leeds Forge, Leeds.

1881. Langdon, William, Oakfields, Kingsbury, London, N.W.

1881. Lange, Frederick Montague Townshend, 3 Prince's Mansions, Victoria Street, Westminster, S.W.

1893. Langford, William, The Oaklands, Hagley Road, Birmingham.

1879. Lapage, Richard Herbert, Oakfield, Langley Avenue, Surbiton, London, S.W.

1890. Last, Lieutenant Arthur John, R.A., Inspector of Ordnance Machinery, The Castle, Cape Town, Cape Colony.

1888. Latham, Baldwin, 13 Victoria Street, Westminster, S.W.; and Duppas House, Old Town, Croydon.

1890. Laurie, Leonard George, Mill Parade, Newport, Monmouthshire.

1867. Lawrence, Henry, 24 Grainger Street West, Newcastle-on-Tyne.

1893. Lawrie, James, Assistant Government Marine Surveyor, Singapore, Straits Settlements.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 65 Osborne Road, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Daniel Layborn and Co., Dutton Street, Liverpool.

1883. Laycock, William S., Victoria Street Works, Sheffield; and Ranmoor, Sheffield. [*Invention, Sheffield.* 907.]

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1892. Lea, Richard Henry, Stoke Green, Coventry.

1895. Lea, William Arthur, 5 Bedford Road, Toronto, Ontario, Canada.

1889. Leaf, Henry Meredith, Burlington Lodge, Streatham Common, London, S.W.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1890. Ledingham, John Machray, Royal Laboratory, Royal Arsenal, Woolwich.

1887. Lee, Cuthbert Ridley, Messrs. C. R. Lee and Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1862. Lee, J. C. Frank, 6 Great Winchester Street, London, E.C.

1892. Lee, Richard John, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1890. Lee, Samuel Edward, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1889. Legros, Lucien Alphonse, 57 Brook Green, Hammersmith, London, W.

1896. Leisse, George Charles, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1883. Leslie, Joseph, 3 Canal Street, North Road, Entally, Calcutta, India.

1878. Lewis, Gilbert, 538 Eccles New Road, Eccles, Manchester.

1884. Lewis, Henry Watkin, Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1895. Lewis, Herbert William, Acting Senior Inspector of Boilers, Custom House, Bombay, India.

1884. Lewis, Sir William Thomas, Bart., Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1894. Liebert, Henry Anton, Messrs. John Holroyd and Co., Perseverance Works, Milnrow, Rochdale.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1891. Lindsay, William Robertson, 1 Lorne Terrace, Forfar Road, Dundee.

1890. Lineham, Wilfrid James, Professor of Engineering and Mechanical Science, The Goldsmiths' Institute, New Cross, London, S.E.; and Jesmond, Leyland Road, Lee, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.; and 3 St. John's Park, Blackheath, London, S.E.

1890. Lister, Robert Ramsbottom, Messrs. Beyer Peacock and Co. Gorton Foundry, Manchester.

1890. Livens, Frederick Howard, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1895. Livingston, James, 30 Great St. Helen's, London, E.C. [*Cinerary, London.*]

1886. Livsey, John Edward, 34 Octavia Street, Battersea, London, S.W.

1867. Lloyd, Charles, 78 Station Road, South Shore, Blackpool.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 90 Whitecross Street, London, E.C.

1894. Lloyd, Sampson Zachary, Managing Director, Engineering Department, Messrs. Nettlefolds, Birmingham [*Nettlefolds, Birmingham.*]; and Areley Hall, Stourport.

1897. Loane, Samuel Joshua, Acting Chief Engineer, Madras Municipality, Municipal Office, Madras, India.

1879. Lockhart, William Stronach, 67 Granville Park, Blackheath, London, S.E.

1884. Logan, Andrew Linton, Bank of Scotland, Crieff.

1890. Logan, John Walker, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester; and P.O. Box 2037, Johannesburg, Transvaal, South Africa.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1894. Longridge, Captain Cecil Clement, 15 George Street, Mansion House, London, E.C.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, 16 Place de la République, Paris.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1888. Low, David Allan, Professor of Engineering, East London Technical College, People's Palace, Mile End Road, London, E.

1885. Low, Robert, Powis Lodge, Vicarage Park, Plumstead.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, General Manager, Barry Graving Dock and Engineering Co., Exchange Buildings, Cardiff. [*Bardock, Cardiff.*]

1891. Lowdon, Thomas, Kingsland Crescent, Barry Docks, B.O., near Cardiff.

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1873. Lucas, Arthur, 27 Bruton Street, New Bond Street, London, W.

1889. Lucy, Arthur John, Meadowcroft, Penn Road, Croydon.

1897. Lucy, Ernest Edward, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.

1886. Lucy, William Theodore, Messrs. Evans, Livock and Co., 130 Calle 25 de Mayo, Buenos Aires, Argentine Republic: (or Thornleigh, Woodstock Road, Oxford.)

1895. Lumsden, Thomas Templeton Mackie, Managing Director, Messrs. James Milne and Son, Milton House Works, Edinburgh.

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1897. Lupton, Hugh, Messrs. Hathorn, Davey and Co., Sun Foundry, Dewsbury Road, Leeds. [*Hathorn, Leeds.* 524.]

1887. Lupton, Kenneth, 6 Jesson Street, Coventry.

1878. Lynde, James Henry, Buckland, Ashton-on-Mersey, near Manchester.

1889. Macallan, George, Works Manager, Great Eastern Railway, Stratford Works, London, E.

1892. Macbean, John James, Messrs. Howarth Erskine and Co., Singapore, Straits Settlements.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1884. MacCarthy, Samuel, Messrs. Lloyd and Lloyd, 90 Cannon Street, London, E.C.; and 18 Adelaide Road, Brockley, London, S.E.

1877. MacColl, Hector, Bloomfield, Belfast.

1897. MacDonald, David Johnstone, South St. Roque's Works, Dundee. [*Medalist, Dundee.* 239.]

1889. Macdonald, James Alexander, Broad Oaks Iron Works, Chesterfield.

1895. MacGarvey, Howard, Lombard Street Works, Dublin.

1892. Mackay, Charles O'Keefe, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1890. Mackay, Joseph, Bangkok Dock Co., Bangkok, Siam: (or care of Messrs. John Birch and Co., 10 Queen Street Place, London, E.C.) [*Mackay, Bangkok.*]

1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 40 Chancery Lane, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1894. Mackie, John, Reading Iron Works, Reading. [*Engineering, Reading.*]

1875. Maclagan, Robert, Blantyre, British Central Africa: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)

1889. MacLay, Alexander, Professor of Mechanical Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock; and 31 Bank Street, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1864. Macnab, Archibald Francis, Tokyo, Japan.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1892. Mactear, James, F.R.S.E., 28 Victoria Street, Westminster, S.W. [*Celestine, London.* 3066.]

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*Offsett, London.*]

1891. Mahon, Major Reginald Henry, R.A., Superintendent, H. M. Shell Factory, Cossipore, Calcutta, India.

1896. Main, William Henderson, Superintendent, Engine Department, H. M. Mint, Bombay, India.

1873. Mair-Rumley, John George (*Life Member*), 43 Palace Court, London, W. [*Ipsum, London.*]

1884. Mais, Henry Coathupe, 2 Prell's Buildings, Collins and Queen Streets, Melbourne, Victoria.

1883. Malan, Ernest de Mérindol, Westinghouse Brake Co., York Road, King's Cross, London, N.

1879. Malcolm, Bowman, Locomotive Engineer, Belfast and Northern Counties Railway, Belfast.

1891. Manisty, Edward, Dundalk Iron Works, Dundalk, Ireland; and 24A Bryanston Square, London, W.

1894. Mann, James Hutchinson, Messrs. Mann and Charlesworth, Canning Works, Dewsbury Road, Leeds. [*Canning, Leeds.* 1335.]

1888. Mano, Bunji, Professor of Mechanical Engineering, Imperial University Tokyo, Japan.

1875. Mansergh, James, 5 Victoria Street, Westminster, S.W.

1894. Mansfield, Edwin, Messrs. Edwin Mansfield and Sons, Whitby Engineering Works, near Chester. [*Mansfield, Whitby, Chester.*]

1891. Manson, James, Locomotive Superintendent, Glasgow and South Western Railway, Kilmarnock.

1897. Mantle, Harry George, Old Level Iron Works, Brierley Hill. [*Hall, Brierley Hill.* 8035.]

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1897. Mapplebeck, Edward, Messrs. John Wilkes, Sons and Mapplebeck, Liverpool Street, Birmingham. [*Wilkes, Birmingham.*]

1878. Marié, Georges, 4 Boulevard des Sablons, Neuilly-sur-Seine, France.

1891. Marks, Edward Charles Robert, 13 Temple Street, Birmingham.

1888. Marks, George Croydon, 18 Southampton Buildings, Chancery Lane, London, W.C. [*Reconstruction, London.*]

1896. Markwick, Alfred Ernest, Superintendent of Machinery, Karachi Municipality, Lawrence Road, Karachi, India.

1884. Marquand, Augustus John, 2 Dock Chambers, Bute Docks, Cardiff. [*Martial, Cardiff.*]

1887. Marriott, William, Engineer and Locomotive Superintendent, Midland and Great Northern Joint Railways, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1896. Marsh, Douglas Earle, Locomotive Department, Great Northern Railway, Doncaster.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Rev. Alfred (*Life Member*), The Vicarage, Feckenham, Redditch.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1890. Marshall, Frank Herbert, Messrs. Wilsons, Pease and Co., Tees Iron Works, Middlesbrough.

1885. Marshall, Henry Dickenson, Messrs. Marshall, Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1897. Marshall, Herbert, Messrs. Marshall, Sons and Co., Britannia Iron Works, Gainsborough.

1871. Marshall, James, Messrs. Marshall, Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Messrs. Chance Brothers and Co., Glass Works, near Birmingham; and Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Pedmore, Stourbridge. [*Marten, Stourbridge.* 8504.]

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1889. Martin, The Hon. James, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Martindale, Warine Ben Hay, 38 Parliament Street, Westminster, S.W.; and Roveoaks, Ingatestone, Essex.

1882. Masefield, Robert, 14 Markham Square, Chelsea, London, S.W.

1884. Massey, George, Post Office Chambers, Pitt Street, Sydney, New South Wales.

1890. Massey, Stephen, Messrs. B. and S. Massey, Openshaw, Manchester.

1893. Massey, William Henry, 25 Queen Anne's Gate, Westminster, S.W.; and Twyford, R.S.O., Berkshire.

1892. Masterton, John Fraser, Locomotive Department, South Eastern Railway, Ashford, Kent.

1894. Mather, George Radford, Messrs. G. R. Mather and Son, Albion Foundry, Wellingborough. [*Mather, Wellingborough.*]

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Queen Dyeing Co., Providence, Rhode Island, United States.

1882. Matheson, Henry Cripps, Enfield, Sunny Gardens, Hendon, London, N.W.

1891. Mathewson, Jeremiah Eugene, Tilghman's Sand-Blast Co., Broadheath, near Manchester.

1886. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1895. Matthews, Thomas, Imperial Iron Works, West Gorton, Manchester.

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1893. Maunsell, Richard Edward Lloyd, Assistant Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, Maxim Nordenfelt Guns and Ammunition Co., 32 Victoria Street, Westminster, S.W.; and 18 Queen's Gate Place, South Kensington, London, S.W.

1859. Maylor, William, Chesterleigh, Albemarle Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1891. McCredie, Arthur Latimer, Mutual Life of New York Buildings, Martin Place, Sydney, New South Wales. [*Ebony, Sydney.* 63.]

1892. McDonald, John, Locomotive Works, Imperial Government Railways, Tokyo, Japan.

1878. McDonald, John Alexander, Assistant Engineer-in-chief, Public Works Department, Perth, Western Australia: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 23 Denbigh Street, London, S.W.; and Rydens, Hersham Road, Walton-on-Thames.

1891. McFarlane, George, Sun Insurance Buildings, 121 West George Street, Glasgow. [*Dunsloy, Glasgow.* 3777.]

1895. McFarlane, James, 10A Spring Gardens, Abbeyhill, Edinburgh.

1895. McGee, Walter, Albion Works, Stoney Brae, Paisley. [137.]

1897. McGlashan, William, Chief Mechanical Engineer, Foundry and Shell Factory, Cossipore, Calcutta, India.

1889. McIntyre, John Henry A., Lecturer on Mechanical Engineering, Allan Glen's School, Glasgow.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 10 Lammas Park Gardens, Ealing, London, W.

1888. McLarty, Farquhar Matheson, 26 Brougham Street, Greenock. [*Unique, Greenock.*]

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow [*Colonial, Glasgow*]; and Rosario, Dalkeith Avenue, Dumbreck, Glasgow.

1896. McPherson, Stewart, Manager, Barnagore Jute Works, Calcutta, India.

1894. McQueen, John, Messrs. John Hetherington and Sons, Vulcan Works, Pollard Street, Manchester.

1891. Meade, Thomas de Courcy, Town Hall, Manchester; and Kenmore, Didsbury, Manchester.

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1881. Meik, Charles Scott, care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1891. Melville, William Charles, Superintendent Engineer, Liverpool Steam Tug Co., 44 Chapel Street, Liverpool.

1888. Melville, William Wilkie, Messrs. Caddy and Co., Daybrook, Nottingham.

1897. Mendizabal, Carlos, General Manager, Altos Hornos Iron and Steel Works, Bilbao, Spain.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Co., 50 Side, Newcastle-on-Tyne. [*William Menzies, Newcastle-on-Tyne. G.P.O.* 200. *Nor. Dis.* 1144.]

1897. Meredith, John, Messrs. Turney and Co., Whitemoor Works, Nottingham.

1894. Merrick, Robert, Warren's Place Iron Works, Cork.

1896. Merrifield, Leonard Lancaster, 19 Abingdon Street, Westminster, S.W.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]

1891. Metcalfe, Frederick Spencer, Pumping Station, Sewage Works, Burton-on-Trent.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 17 Victoria Street, Westminster, S.W.

1891. Middleton, Robert, Sheepscar Foundry, Leeds.

1891. Middleton, Robert Thomas, Superintendent of Bridge Works, Bombay Baroda and Central India Railway, Bombay, India.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1893. Millar, Jackson, Messrs. Riley Hargreaves and Co., 11 Merchant Road, Singapore, Straits Settlements: (or care of J. R. Allan, 93 Hope Street, Glasgow.)

1889. Miller, Adam, 50 Lime Street, London, E.C.

1885. Miller, Harry William, Princess Estate and Gold Mining Co., P.O. Box 1366, Johannesburg, Transvaal, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, 7 Tower Buildings N., Water Street, Liverpool.

1893. Milligan, William Scott, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1893. Millington, Frederick Handel, Manager, Patent Pulp Manufacturing Co., Thetford; and Mill House, Thetford.

1885. Millis, Charles Thomas, Principal, Educational Department, Borough Road Polytechnic, London, S.E.

1897. Mills, William, Atlas Works, Bonner's Field, Sunderland. [*Engineer, Sunderland.* 552.]

1887. Milne, William, Castle Buildings, West Street, Durban, Natal [*Metallic, Durban*]; and The Oaks, 52 Queen Street, Durban, Natal.

1892. Mitcheson, George Arthur, Longton, Staffordshire. [*Mitcheson, Longton.* 445.]

1897. Miyabara, Constructor Captain Jiro, Naval Department, Tokyo, Japan.

1870. Moberly, Charles Henry, 33 Bennett Park, Blackheath, London, S.E.

1896. Moffatt, Alexander Charles, Messrs. Moffatt and Eastmead, 39 Victoria Street, Westminster, S.W. [*Hoistway, London.*]

1885. Moir, James, Boyd's Ice Factory, Calicut Street, Bombay, India. [*Frigid, Bombay.*]

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., The Manor House, Bexley, S.O., Kent.

1882. Molesworth, James Murray, Aberdeen House, Upper Holly Walk, Leamington.

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1897. Monkhouse, Edward Wyndham, Messrs. Burstall and Monkhouse, 14 Old Queen Street, Westminster, S.W. [*Advisedly, London.*]

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S.O., Kent.

1876. Moore, Joseph, 1099 Adeline Street, Oakland, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines, 13 Clairmont Gardens, Glasgow.)

1895. Moore, William James Perry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.

1897. Morcom, Alfred, Managing Director, Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1880. Moreland, Richard, Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1889. Morgan, David John, 12 Windsor Road, Barry, near Cardiff.

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1896. Morley, Herbert William, Messrs. Cole, Marchent and Morley, Prospect Foundry, Bradford. [*Cole, Bradford.* 690.]

1895. Morrin, Richard, Superintendent Engineer, Messrs. Lamport and Holt, 21 Water Street, Liverpool.

1888. Morris, Charles, Messrs. Jessop and Co., Phœnix Iron Works, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1890. Morris, Francis Sanders, 4 Trafalgar Square, London, W.C.

1890. Morris, John Alfred (*Life Member*), Empire Engineering Co., Empire Works, Failsworth, Manchester.

1892. Morton, David Home, 95 Bath Street, Glasgow.

1858. Mountain, Charles George, 35 Exchange Buildings, Stephenson Place, Birmingham.

1886. Mountain, William Charles, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne [*Esco, Newcastle-on-Tyne.* 432.]; and 9 St. George's Terrace, Jesmond, Newcastle-on-Tyne.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Central Marine Engine Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherbourne Street, Strangeways, Manchester.

1876. Muirhead, Richard, Kentish Engineering Works, Maidstone. [*Muirhead, Maidstone.*]

1890. Müller, Henry Adolphus, Locomotive Superintendent, Municipal Railway, 3 North Road, Entally, Calcutta, India.

1890. Mumford, Charles Edward, St. Andrew's Works, Bury St. Edmunds.

1897. Munro, Edward May, Messrs. H. Brecknell, Sons and Munro, Lawrence Hill, Bristol. [*Brecknell, Bristol.* 467.]

1890. Munro, John, Professor of Mechanical Engineering, Merchant Venturers' Technical College, Unity Street, Bristol.

1890. Munro, Robert Douglas, Chief Engineer, Scottish Boiler Insurance and Engine Inspection Co., 13 Dundas Street, Glasgow.

1889. Münster, Bernard Adolph, Engineer, Yokohama, Japan.

1891. Murdoch, Robert Macmillan, Phœnix Metal Die and Engineering Co., 40 Coin Street, Stamford Street, London, S.E.

1890. Murray, Alexander John, Chief Mechanical Engineer, Government Gun-Powder Factory, Kirkee, Bombay, India.

1890. Murray, Kenneth Sutherland, Brin's Oxygen Works, 69 Horseferry Road, Westminster, S.W.

1894. Murray, Thomas Roberts, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow.

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1897. Musker, Arthur, Messrs. C. and A. Musker, Dundas Street, Bootle, Liverpool. [*Fulgor, Liverpool.* 3704.]

1897. Musker, Charles, Messrs. C. and A. Musker, Dundas Street, Bootle, Liverpool. [*Fulgor, Liverpool.* 3704.]

1888. Myers-Beswick, William Beswick (*Life Member*), 14 Victoria Street, Westminster, S.W.

1889. Nash, Thomas, Sheffield Testing Works, Blonk Street, Sheffield; and Guzerat House, Nether Edge, Sheffield.
1889. Nasmith, Joseph, 61 Barton Arcade, Manchester.
1888. Nathan, Adolphus, Messrs. Larini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.
1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.
1883. Neate, Percy John, 16 The Banks, High Street, Rochester.
1889. Needham, Joseph Edward, Patent Office, 25 Southampton Buildings, London, W.C.
1892. Nelson, Arthur David, Hay and Lackey Streets, Sydney, New South Wales. [*Nelson, Sydney.* 160.]
1884. Nelson, John, Contractor's Office, 8 Lendal, York. [*Nelson, York.*]
1881. Nesfield, Arthur, 14 Water Street, Liverpool.
1890. Newton, Percy, 23 Alexander Square, South Kensington, London, S.W.
1897. Newton, Thomas George, Messrs. W. Summerscales and Sons, Phœnix Foundry, Keighley.
1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chili.
1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.
1894. Nicholson, John Rumney, Engineers' Office, Port Talbot Graving Dock, Port Talbot.
1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.
1884. Noakes, Walter Maplesden, 73 Clarence Street, Wynyard Square, Sydney, New South Wales.
1892. Norris, William, Messrs. Coulthard and Co., Preston.
1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.
1883. North, Gamble, Pisagua, Chile: Queenswood, Eltham: (or 57 Gracechurch Street, London, E.C.)
1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]
1888. Norton, William Eardley, 8 Great George Street, Westminster, S.W.

1885. Oakes, Sir Reginald Louis, Bart., Société Anonyme La Métallurgique, 1 Place de Louvain, Bruxelles, Belgium.
1887. O'Brien, Benjamin Thompson, 34 Catharine Street, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1890. Ockendon, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. O'Connor, Charles, 20 Lyra Road, Waterloo, Liverpool.

1888. O'Donnell, John Patrick, 70 and 71 Palace Chambers, 9 Bridge Street, Westminster, S.W.; and Fingal, Hemmelton Road, Bromley, Kent. [*ODonnell, London.* 3378.]

1889. Ogden, Fred, Patent Office, 25 Southampton Buildings, London, W.C.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C. [*Oglio, London.* 2463.]

1894. Oka, Saneyasu, 141, 1 Chome, Funakori Cho, Osaka, Japan.

1893. Oke, Francis Robert, 5 Coppenhall Terrace, Crewe. [*Oke, Crewe.*]

1875. Okes, John Charles Raymond, 63 Queen Victoria Street, London, E.C. [*Oaktree, London.*]

1882. Orange, James, Messrs. Danby Leigh and Orange, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1897. Orr, Charles Roger, Manager, Gourepore Jute Manufacturing and Linseed Crushing Co., Calcutta; and Naihati, Bengal, India.

1892. Osmond, Frederick John, The Tower, Bagot Street, Birmingham. [*Osmond, Birmingham.* 550.]

1867. Oughterson, George Blake, Broadway House, 2 Broadway, Westminster, S.W.; and 40 Blessington Road, Lewisham, London, S.E.

1889. Owen, Thomas, Midland Railway, Derby.

1897. Owens, Philip Robert, Messrs. Donaldson and Owens, 25 Tower Buildings, Liverpool. [*Torpedo, Liverpool.*]

1877. Panton, William Henry, Messrs. Dorman Long and Co., Middlesbrough.

1872. Parker, Thomas, Gorton House, Gorton, near Manchester.

1888. Parker, Thomas, Jun., Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester; and Gorton House, Gorton, near Manchester.

1891. Parker, Thomas, F.R.S.E., Manor House, Tettenhall, Wolverhampton. [*Parker, Tettenhall.*]

1895. Parkinson, Hudson Clough, Engineer's Office, Cumberland Basin, Bristol Docks, Bristol.

1884. Parlane, William, Manager, Hong Kong Ice Company, Hong Kong, China: (or Ladyton Cottage, Bonhill, Dumbartonshire.)

1892. Parratt, William Heather, Rose Hall, Canje Creek, Berbice, British Guiana.

1892. Parrott, Thomas Henry, Fairlight, Westfield Road, Edgbaston, Birmingham.

1886. Parry, Alfred, Messrs. Parry and Co., Vulcan Iron Works, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1889. Parry, Evan Henry, care of Wolhuter Gold Mines, P. O. Box 860, Johannesburg, Transvaal, South Africa.

1878. Parsons, The Hon. Richard Clere, Messrs. Bateman Parsons and Bateman, 39 Victoria Street, Westminster, S.W. [*Outfall, London.* 3233.]; and 48 Prince's Gardens, London, S.W.

1886. Passmore, Frank Bailey, Suffolk House, 5 Laurence Pountney Hill, London, E.C. [*Knarf, London.*]

1896. Patchell, William Henry, Engineer-in-chief, Charing Cross and Strand Electricity Supply Corporation, 15 Maiden Lane, Covent Garden, London, W.C.

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1881. Patterson, Anthony, Dowlais Iron Works, Cardiff; and 9 Glossop Terrace, Cardiff.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1891. Pattison, Joseph, 123 Bute Street, Cardiff.

1891. Paul, Matthew, Jun., Messrs. Matthew Paul and Co., Levenford Works, Dumbarton.

1891. Paulson, Scott, City Flour Mills, Cape Town, Cape Colony: (or care of Dr. Paulson, Mount Sorrel, near Loughborough.)

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, 87 East Hill, Colchester.

1890. Peacock, Francis, Egyptian Delta Light Railway, Damanhour, Lower Egypt.

1890. Peacock, James Albert Wells, Egyptian Delta Light Railway, Damanhour, Lower Egypt.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1873. Pearce, Richard, Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India.

1897. Pearce, Thomas, Managing Director, Messrs. Johns and Waygood, Sturt Street, South Melbourne, Victoria: (or care of Messrs. C. R. Lee and Co., Suffolk House, Laurence Pountney Hill, London, E.C.)

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1897. Penn, Frederick James, Messrs. Westley Richards and Co., 82 High Street, Birmingham.

1873. Penn, John, M.P., Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1893. Philip, William Littlejohn, Managing Director, Messrs. Spencer and Co., Melksham Foundry, Melksham.

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Lionel, Messrs. Wernher, Beit and Co., 120 Bishopsgate Street Within, London, E.C.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and 47 Sussex Place, Onslow Gardens, London, S.W. [*Phicycle, London.*]

1890. Phillips, Walter, West India House, Leadenhall Street, London, E.C. [*Philology, London.*]

1882. Phipps, Christopher Edward, Locomotive Superintendent, Madras Railway, Perambore Works, Madras, India.

1894. Pickering, Jonathan, Resident Engineer, Colonial Sugar Refining Co., Sydney, New South Wales; and Broadwater, Richmond River, New South Wales: (or care of John Pickering, 1 Hillend Gardens, Partick Hill, Glasgow.)

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, 14 Fitzwilliam Place, Dublin.

1888. Pilkington, Herbert, Sheepbridge Iron Works, Chesterfield.

1883. Pillow, Edward, Director of Technical Instruction for Norfolk, Shire Hall, Norwich; and 2 Carlton Terrace, Mill Hill Road, Norwich.

1892. Pinder, Charles Ralph, New Rietfontein Estate and Gold Mines, P. O. Box 897, Johannesburg, Transvaal, South Africa.

1892. Pirie, George, 3 Church Terrace, Burrage Road, Plumstead.

1888. Pirrie, The Right Hon. William James, Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Chief Engineer, Linotype Co., Broadheath, near Manchester; and Regent Road, Altrincham.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester [*Atlas, Gloucester.*]; and Somerset House, Gloucester. [*Platt, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe (*Life Member*), Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John (*Life Member*), Clydach Foundry, near Swansea.

1892. Pogson, Alfred Lee, Engineer-in-Chief, Harbour Trust Board and Works, Madras, India.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1894. Poland, William, Messrs. William Poland and Co., King's Bench Walk, Southwark, London, S.E. [*Determine, London.*]

1893. Pollit, Edward Ernest, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1894. Pollitt, Harry, Chief Locomotive Engineer, Great Central Railway, Gorton, Manchester. [*Traction, Gorton.*]

1886. Pollock, James, 22 Billiter Street, London, E.C. [*Specific, London.*]

1876. Pooley, Henry, Homestead, Radnor Drive, Liscard, near Liverpool.

1890. Potter, William Henry, Brougham Chambers, Wheeler Gate, Nottingham.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 117 Camberwell Grove, London, S.E.

1878. Powel, Henry Coke, Tintern House, 64 Burnt Ash Hill, Lee, London, S.E.

1874. Powell, Thomas, Brynteg, Neath.

1891. Powles, Henry Handley Pridham, 152 Oakley Street, Chelsea, London, S.W.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1892. Pratt, Middleton, 6 Richmond Terrace, New Brighton, near Birkenhead.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1890. Preece, William Henry, C.B., F.R.S., General Post Office, St. Martin's-le-Grand, London, E.C.

1882. Presser, Ernest Charles Antoine, Barquillo 26, Madrid.

1897. Price, Charles Edwin, Messrs. Price and Corneille, 15 Victoria Street, Westminster, S.W. [*Proclino, London.*]

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 49 Queen Victoria Street, London, E.C. [*Indices, London.*]

1896. Price, James, Harbour Engineer, 9 Lapp's Quay, Cork.

1866. Price, John, 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1890. Price, John, Inspecting Engineer, Workington.

1889. Price, John Bennett, 313 Temple Chambers, Brazennose Street, Manchester; and Wyresdale, Wilbraham Road, Chorlton-cum-Hardy, near Manchester.

1859. Price-Williams, Richard, 32 Victoria Street, Westminster, S.W. [*Spandrel, London.*]

1886. Price-Williams, Seymour William, 5 Victoria Street, Westminster, S.W.

1895. Proctor, Charles Faraday, Fittings Department, Edison and Swan Co., Ponders End, London, N.

1894. Pryce, Henry James, Locomotive Superintendent, North London Railway, Bow Road Works, London, E.

1890. Pugh, Charles Henry, Whitworth Works, Rea Street South, Birmingham.

1887. Pullen, William Wade Fitzherbert, Fairley Villa, Oxford Road, Putney, London, S.W.

1884. Puplett, Samuel, 47 Victoria Street, Westminster, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1887. Pyne, Sir Thomas Salter, C.S.I., care of H.H. the Ameer of Afghanistan, Kabul: (or care of E. C. Clarke, Foreign Office, Government of India, Simla or Calcutta, India: or care of Edmund Neel, C.I.E., India Office, Whitehall, London, S.W.)

1892. Quentrall, Thomas, H.M. Inspector of Mines, Kimberley, South Africa.

1893. Quirk, Edward, Chief Mechanical Engineer, Trinity House, London, E.C.

1870. Radcliffe, William (*Life Member*), Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield. [*Radford, Sheffield.*]

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Rafarel, William Claude, Gorwell House, Barnstaple.

1885. Rainforth, William, Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]

1892. Ramsay, William, Superintendent Engineer, Scottish Oriental Steamship Co., Hong Kong, China.

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1894. Ramsbottom, John Goodfellow, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 32 Victoria Street, Westminster, S.W. [*Ransomes Rapier, Westminster.*]

1888. Rapley, Frederick Harvey, 1208 Havemeyer Building, New York, United States.

1889. Ratcliffe, James Thomas, Baumwoll-Manufactur von Izr. K. Poznanski, Lodz, Russian Poland.

1883. Rathbone, Edgar Philip, South African Argosy Association, 18 Bishopsgate Street Within, London, E.C.

1867. Ratliffe, George, 7A Laurence Pountney Hill, London, E.C.

1893. Raven, Vincent Litchfield, Locomotive Department, North Eastern Railway, Darlington.

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham [*Metro, Birmingham.*]; and The Mount, Erdington, near Birmingham.

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Sons, West Docks, South Shields. [*Readhead, South Shields.* G.P.O. 14. Nat. 2024.]

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1895. Redit, David, Downham Market, Norfolk.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 64 Mark Lane, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1894. Reed, Joseph William, Manager, Engine Works Department, Palmer's Shipbuilding and Iron Works, Jarrow.

1891. Reed, Thomas Alfred, Bute Docks, Cardiff. [*Steam, Cardiff.* 171.]

1897. Reid, Andrew Thomson, Messrs. Neilson, Reid and Co., Hyde Park Locomotive Works, Glasgow. [*Neilson, Springburn.* 822.]

1891. Reid, Hugh (*Life Member*), Messrs. Neilson, Reid and Co., Hyde Park Locomotive Works, Glasgow. [*Neilson, Springburn.* 822.]

1897. Reid, John (*Life Member*), Messrs. Neilson, Reid and Co., Hyde Park Locomotive Works, Glasgow. [*Neilson, Springburn.* 822.]

1889. Rendell, Alan Wood, Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or 42 Goldhurst Terrace, South Hampstead, London, N.W.)

1890. Rendell, Samuel, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and New Mills, near Stockport.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, 49 Queen's Gate, London, S.W.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1883. Reunert, Theodore (*Life Member*), Box 209, Kimberley, South Africa; Box 92, Johannesburg, Transvaal, South Africa: (or care of Messrs. Findlay, Durham and Brodie, 43–46 Threadneedle Street, London, E.C.)

1895. Rew, James Henry, Margaretta, Dumbreck, Glasgow.

1879. Reynolds, George Bernard, care of Messrs. Maclain, Watson and Co., Batavia, Java: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1890. Rice, Thomas Sydney, Aldermary House, 60 Watling Street, London, E.C. [*Ricto, London.*]

1866. Richards, Edward Windsor, Low Moor Iron Works, near Bradford.

1897. Richards, Henry William Hall, Messrs. W. Richards and Son, Phœnix Iron Works, Leicester. [*Richards, Leicester.* 89.]

1884. Richards, Lewis, Bedlinog Hall, Bedlinog, Treharris, R.S.O., Glamorganshire.

1895. Richardson, Andrew, Messrs. Campbell and Calderwood, Soho Engine Works, Paisley.

1892. Richardson, Harry Alfred, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1891. Richardson, John Scott, 302 Calle Balcarce, Buenos Aires, Argentine Republic: (or care of J. W. Champness Richardson, Lindum, Pattison Road, Child's Hill, London, N.W.)

1887. Richardson, Sir Thomas, M.P., Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Swalwell Steel Works, Newcastle-on-Tyne.

1893. Ridley, James Taylor, 6 Ruthin Gardens, Cardiff.

1887. Riekie, John, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India.

1874. Riley, James, General Manager, Glasgow Iron and Steel Company, 36 St. Vincent Place, Glasgow. [*Ingot, Glasgow.* 825.]

1894. Riley, Joseph Hacking, Elton Iron Works, Bury, Lancashire.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1884. Ripper, William, Professor of Mechanical Engineering, Technical Department, University College, St. George's Square, Sheffield.

1879. Rixom, Alfred John, 108 Park Road, Loughborough.

1891. Roberts, Hugh Jorwerth, Messrs. Burn and Co., Howrah Iron Works, Howrah, Calcutta, India: (or care of R. P. Roberts, 3 Osborne Road, Liscard, near Liverpool.)

1887. Roberts, Thomas, Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, 13 Craven Hill Gardens, Hyde Park, London, W.

1879. Robertson, William, Newlyn, Eton Avenue, Hampstead, London, N.W.

1894. Robinson, Arthur Maurice, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1897. Robinson, Charles Arthur, Messrs. Robinson, Sadler and Co., 20 Ebrington Street, Plymouth. [506.]

1894. Robinson, Charles John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1890. Robinson, Frederick Arthur, Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C. [*Farrago, London.*]

1874. Robinson, Henry, Professor of Civil Engineering, King's College, Strand, London, W.C.; and 13 Victoria Street, Westminster, S.W.

1895. Robinson, James, 10 India Buildings, 14 Cross Street, Manchester.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow and Westwood Hall, near Leek.

1886. Robinson, John, 8 Vicarage Terrace, Kendal.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow. [*Loco, Glasgow.* 3210.]

1891. Robinson, John George, Locomotive and Carriage Engineer, Waterford and Limerick Railway, Limerick.

1892. Robinson, Leslie Stephen, 28 Victoria Street, Westminster, S.W. [*Eyebolts, London.*]

1894. Robinson, Mark Heaton, Messrs. Willans and Robinson, Victoria Works, Rugby [*c/o Willans, Rugby.*]; and Overslade, Rugby.

1890. Robinson, Sydney Jessop, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1895. Robinson, William, Professor of Mechanical and Electrical Engineering, University College, Nottingham.

1897. Robson, George, 14 Union Court, Old Broad Street, London, E.C.

1891. Roche, Francis James, care of W. F. Stock, Glenelg, South Australia.

1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.

1885. Rogers, Henry John, Watford Engineering Works, Watford. [*Mechanical, Watford.* 35.]

1892. Ronald, Henry, Small Arms Ammunition Factory, Dum Dum, near Calcutta, India.

1889. Rosenthal, James Hermann, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1893. Rounthwaite, Henry Morrison, Messrs. Maudslay Sons and Field, 110 Westminster Bridge Road, London, S.E.; and 15 Nicosia Road, Wandsworth Common, London, S.W.

1856. Rouse, Frederick, Locomotive Department, Great Northern Railway, Peterborough.

1878. Routh, William Pole, Oakfield, Southern Hill, Reading.

1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.

1892. Rowe, Almond, Senior Government Marine Surveyor, Singapore, Straits Settlements.

1891. Rowland, Bartholomew Richmond, Messrs. Luke and Spencer, Broadheath, near Manchester.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, Managing Director, Mercantile Pontoon Co., Roath Dock, Cardiff. [*Mercantile, Cardiff.* G.P.O. 33; Nat. 30.]

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1892. Sainsbury, Francis Charles Barrett, Chief Engineer, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1859. Salt, George, 8 Welbeck Street, Cavendish Square, London, W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, The Right Hon. Sir Bernhard, Bart., F.R.S., Britannia Iron Works, Banbury; 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1890. Sandberg, Christer Peter, 19 Great George Street, Westminster, S.W.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.

1871. Sanders, Richard David, Hartfield House, Eastbourne.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1891. Sands, Harold, Craythorne, Tenterden, Ashford, Kent.

1894. Sankey, Captain Matthew Henry Phineas Riall, Messrs. Willans and Robinson, Victoria Works, Rugby. [*c/o Willans, Rugby.*]

1874. Sauvée, Albert, Union Works, 60 Park Street, Southwark, London, S.E. [*Sovez, London.* Hop 213.]

1891. Savill, Arthur Slater, Exhaust Steam Injector Company, 4 St. Ann's Square, Manchester.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]; and North Court, Hassocks, R.S.O., Sussex.

1893. Saxon, Alfred, Openshaw Engineering Works and Examiner Buildings, Manchester. [959 and 3904.]

1894. Saxon, George, Openshaw Engineering Works and Examiner Buildings, Manchester. [959 and 3904.]

1894. Saxon, James, Openshaw Engineering Works and Examiner Buildings, Manchester. [959 and 3904.]

1869. Scarlett, James, Messrs. E. Green and Son, 2 Exchange Street, Manchester; and Stamford Road, Bowdon, R.O., near Altrincham.

1890. Schofield, George Andrew, General Manager, Sicilian Railways, Palazzo Brijuccia, Palermo, Sicily: (or care of I. D. Schofield, Oakfield, Alderley Edge, Cheshire.)

1886. Scholes, William Henry, 1255 n/n Rivadavia, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W. [*Schönheyder, London.*]

1880. Schram, Richard, Cannon Street House, London, E.C. [*Schram, London.*]

1890. Schroller, William, 6 Old Elvet, Durham. [*Bulumatari, Durham.*]

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1891. Scott, Arthur Forbes, 67 Swan Arcade, Bradford.

1882. Scott, Charles Herbert, Messrs. Summers and Scott, High Orchard Iron Works, Gloucester.

1890. Scott, Frederick McClure, 89 Victoria Street, Liverpool.

1891. Scott, F. Walter, Messrs. George Scott and Son, 44 and 46 Christian Street, London, E. [*Thirty-four, London.* 4390.]

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1891. Scott, Henry John, Glendon Engine Works, Kettering. [*Engine, Kettering.*]

1881. Scott, James, care of Messrs. Reid and Acutt, Smith Street, Durban. Natal: (or Douglasfield, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1894. Scott, Robert, H. M. Mint, Calcutta, India.

1891. Scott, Robert Julian, Professor of Engineering, New Zealand University. Canterbury College, Christchurch, New Zealand.

1861. Scott, Walter Henry, Great Western of Brazil Railway, Pernambuco. Brazil: (or care of H. Eaton, 75 Tulse Hill, London, S.W.)

1896. Scriven, Charles, Leeds Old Foundry, Leeds.

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay. Port Office, Bombay, India.

1892. Seaman, Charles Joseph, 134 High Street, Stockton-on-Tees.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1891. Selby, Millin, 2 Rue du Lac, Bruxelles, Belgium.

1882. Selfe, Norman, 279 George Street, Sydney, New South Wales.

1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1896. Sennett, Alfred Richard, The Chalet, Portinscale Road, Putney, London, S.W.

1894. Seymour, Louis Irving, Messrs. H. Eckstein and Co., P.O. Box 149. Johannesburg, Transvaal, South Africa.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster; and 6 Victoria Street, Westminster, S.W.

1894. Shand, John, Heath Villa, Peterculter, Aberdeen.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1891. Sharp, Henry, 23 College Hill, London, E.C.; and 1 Whitehall Gardens, London, S.W.

1897. Sharp, John, Bolton Iron and Steel Works, Bolton. [*Hammer. Bolton.* 161.]

1895. Sharp, John Hutchinson, Messrs. Sharp, Stewart and Co., Atlas Works, Glasgow.

1875. Sharp, Thomas Budworth, Consulting Engineer, Muntz Metal Works, Birmingham; and County Chambers A, Martineau Street, Birmingham. [*Budworth, Birmingham.*]

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1890. Sheldon, Harry Cecil, Messrs. Boult and Wade, 63 Long Row, Nottingham. [*Boult, Nottingham.* 645.]

1891. Shenton, James, Messrs. Tinker Shenton and Co., Hyde Boiler Works, Hyde, near Manchester.

1892. Shepherd, James, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1861. Shepherd, John, 45 Regent Park Terrace, Headingley, Leeds.

1897. Shepherd, John Lupton, Messrs. Shepherd, Hill and Co., Union Foundry, Hunslet Road, Leeds. [*Shepherd Hill, Leeds.* 1397.]

1875. Sheppard, Herbert Gurney, Chief Engineer, Assioot-Girgeh Railway, Assioot, Upper Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1888. Shin, Tsuneta, Director, Ishikawajima Shipbuilding and Engineering Co., Tokyo, Japan.

1892. Shirlaw, Andrew, Suffolk Works, Oozells Street, Birmingham. [*Shirlaw, Birmingham.*]

1889. Shone, Isaac, 47 Victoria Street, Westminster, S.W.

1890. Shoosmith, Harry, 52 Mark Lane, London, E.C.

1890. Shore, Alfred Thomas, Government Inspector of Steam Boilers, Custom House, Bombay, India.

1893. Shroff, Adurjee Burjorjee, Chief Engineer, Sassoon Spinning Mills, Bombay, India.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1891. Siemens, Alexander (*Life Member*), 12 Queen Anne's Gate, Westminster, S.W.

1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1885. Simpson, James Thomas, Superintending Engineer, Public Works Department, Toungoo, Burma.

1882. Simpson, John Harwood, 1 Hargwyne Street, Brixton, London, S.W.

1889. Sinclair, Nisbet, 11 Randolph Gardens, Crow Road, Partick, Glasgow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1891. Sinclair, Russell, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales.

1881. Sisson, William, Quay Street Iron Works, Gloucester. [*Sisson, Gloucester.*]

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1892. Slight, George Henry, Sub-Director of Lighthouses, Valparaiso, Chile: (or care of George H. Slight, Sen., Waldean, Crofts Lea Park, Ilfracombe.)

1885. Slight, William Hooper, Messrs. W. Henderson and Co., Soerabaya, Java: (or care of G. H. Slight, 64 Cromwell Road, Fitzhugh, Southampton.)

1891. Sloan, Robert Alexander, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1886. Small, James Miln, Messrs. Urquhart and Small, 17 Victoria Street, Westminster, S.W.

1897. Smallman, Herbert Spencer, Globe Tube Works, Wednesbury. [*Tubes, Wednesbury.* 6504.]

1889. Smelt, John Dann, Argentine Great Western Railway, 4 Finsbury Circus, London, E.C.

1879. Smith, Charles Hubert, Board of Trade Surveyors' Office, Leith.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1893. Smith, John, Salford Works, Richard Street, Birmingham. [*Profiler, Birmingham.* 2540.]

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1891. Smith, John Reney, Messrs. Harvey and Bower, 16 Seaton Buildings, 17 Water Street, Liverpool. [*Inspecting, Liverpool.* 6204.]

1890. Smith, John Windle, Messrs. Thomas Drysdale and Co., 438 Calle Moreno, Buenos Aires, Argentine Republic: (or care of Edward Smith, The "Lock," Gainsborough.)

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 47 Victoria Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, Ordsal Station Electrical Works, Salford, Manchester.

1881. Smith, Professor Robert Henry, Ellerslie, Brunswick Road, Sutton, Surrey.

1897. Smith, Robert Walker, Works Manager, New Enfield Cycle Co., Hunt End Works, Redditch.

1896. Smith, Roger Thomas, 7 Gordon Street, Gordon Square, London, W.C.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1890. Smith, William, London and Manchester Plate Glass Co.. Sutton, St. Helen's, Lancashire.

1894. Smith, William, Roads Bridges and Sewerage Department, Sewerage Construction Branch, Public Works Office, Sydney, New South Wales.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester. [*Gresley, Manchester.* 564.]

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, F.R.S., Ennerdale Hall, Frizington, near Carnforth.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham near Darlington.

1897. Snoxell, George Edgar, Messrs. Heath, Snoxell and Co, Apollo Iron Works, Blews Street, Birmingham. [*Snoxell, Birmingham.* 1460.]

1895. Somers, Walter, Haywood Forge, Halesowen, near Birmingham.

1887. Sorabji, Shapurji, Messrs. Shapurjee and Ratanshaw, 49 Leadenhall Street London, E.C. [*Ratanshaw, London.*]

1889. Souter-Robertson, David, Assistant Superintendent, Government Cana Foundry and Workshops, Roorkee, North Western Provinces, India.

1885. Southwell, Frederick Charles, Messrs. F. C. Southwell and Co., 75 Southwark Street, London, S.E. [*Prevailing, London.*]

1877. Soyres, Francis Johnstone de, 4 Leicester Place, Clifton, Bristol.

1893. Spence, Arthur William, Manager, Cork Street Foundry and Engineering Works, Dublin.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1878. Spencer, Alfred G., Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1896. Spencer, Charles James, 80 Queen Victoria Street, London, E.C.

1892. Spencer, Henry Bath, 91 Haworth's Buildings, Cross Street, Manchester. [*Concentration, Manchester.*]

1877. Spencer, John, Globe Tube Works, Wednesbury; and 14 Great St. Thomas Apostle, London, E.C. [*Tubes, Wednesbury. Tubes, London.* 6504.]

1897. Spencer, John, Atlas Works, Keighley. [*Spencer, Engineer, Keighley.* 118.]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Broadheath, near Manchester; and The Hill, Teignmouth.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1897. Spencer, Thomas Harris, Globe Tube Works, Wednesbury. [*Tubes, Wednesbury.* 6504.]

1891. Spencer, William, Messrs. James Spencer and Co., Chamber Iron Works, Hollinwood, near Manchester.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India; and 200 Portsdown Road, Maida Vale, London, W.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1895. Sprague, Ernest Headly, Imperial Tientsin University, Tientsin, China.

1896. Spring, Francis Joseph Edward, C.I.E., Government Consulting Engineer for Railways, Madras, India.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1897. Stagg, William, Canons' Marsh Gas Works, Bristol.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W. [3117.]

1888. Stanley, Harry Frank, Messrs. H. Pontifex and Sons, Farringdon Works, Shoe Lane, London, E.C.; and 75 Ridge Road, Crouch End, London, N.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.

1884. Stanton, Frederic Barry, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1897. Steele, James, Works Manager, Messrs. R. Y. Pickering and Co., Wishaw, near Glasgow.

1868. Stephenson, George Robert, Ben Braich, Tilehurst Road, Reading.

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]

1888. Stephenson-Peach, William John, Askew Hill, Repton, Burton-on-Trent.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]: and 28 Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1891. Stevens, James, 9 and 11 Fenchurch Avenue, London, E.C.

1894. Stevens, Thomas, 37 and 38 Mark Lane, London, E.C.

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.

1892. Stevinson, Thomas, The Nook, Nailsworth, near Stroud, Gloucestershire.

1893. Steward, George Richard, 15 Queen Street, Queen Victoria Street, London, E.C.

1887. Stewart, Andrew, 41 Oswald Street, Glasgow.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]; and Egerton Lodge, Queen's Road, Tunbridge Wells.

1892. Still, William Henry, Hudjuff, Aden, Arabia.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1896. Stirling, Patrick, Great Northern Railway, Doncaster.

1888. Stirling, Robert, Locomotive Department, North Eastern Railway, Gateshead.

1893. Stockton, Joseph Sadler, Lyndhurst, Waverley Road, Kenilworth.

1875. Stoker, Frederick William, 6 Consolidated Gold Fields Buildings, P.O. Box 353, Johannesburg, Transvaal, South Africa.

1892. Stone, Edward Herbert, Chief Engineer, East Indian Railway, Calcutta, India.

1887. Stone, Frank Holmes, G. P. O., Freetown, Sierra Leone.

1894. Stone, Sidney, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham.

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1888. Strachan, James, 70 Frederick Street, Gray's Inn Road, London, W.C.

1892. Strachan, John, Craigisla, Penylan, Cardiff.

1888. Straker, Sidney, Messrs. Straker Whitworth and Co., 139 Cannon Street, London, E.C [*Rhomboidal, London.*]; and Marazion, Bromley Hill, Kent.

1897. Strickland, Frederic, Messrs. Simpson, Strickland and Co., Dartmouth.

1895. Stromeyer, Johann Philipp Edmond Charles, Manchester Steam Users' Association, 9 Mount Street, Manchester.

1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil.

1873. Strype, William George, 115 Grafton Street, Dublin. [*Strype, Dublin.*]

1890. Stutzer, Waldemar, Koltchugin Brass and Copper Mill Co., Alexandrov Station, Jaroslav Railroad, Russia.

1882. Sugden, Thomas, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1890. Sulzer, Jacob, Messrs. Sulzer Brothers, Winterthur, Switzerland.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, 36 Bedford Street, Strand, London, W.C.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1882. Swaine, John, 9 Miles Road, Clifton, Bristol.

1884. Swan, Joseph Wilson, F.R.S., 57 Holborn Viaduct, London, E.C.; and 58 Holland Park, London, W.

1897. Swinburne, George, 99 Queen Street, Melbourne, Victoria.

1882. Swinburne, Mark William, Wallsend Brass Works, Newcastle-on-Tyne; and 117 Park Road, Newcastle-on-Tyne. [*Bronze, Wallsend.*]

1864. Swindell, James Swindell Evers, Homer Hill, Cradley, Staffordshire.

1890. Swinerd, Edward, Westwood, 27 Waldegrave Road, Norwood, London, S.E.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and The Corner House, Shortlands, S.O., Kent.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1889. Tangye, Harold Lincoln, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1895. Tannett, John Croysdale, Messrs. Fullerton, Hodgart and Barclay, Vulcan Works, Paisley.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1893. Tasker, Frederick, Messrs. Tasker Sons and Co., New Station Road, Sheffield. [*Tasker, Sheffield.* 1005.]

1876. Taunton, Richard Hobbs, 10 Coleshill Street, Birmingham.

1874. Taylor, Arthur, Manager, Sociedad Anglo-Vasca, Villanueva del Duque, Provincia de Cordoba, Spain: (or 21 Victoria Road, Kensington, London, W.)

1873. Taylor, John, 324 Mansfield Road, Nottingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, Paris; and 21 Victoria Road, Kensington, London, W.

1893. Taylor, Robert, Jun., Works Manager, Messrs. Asa Lees and Co., Soho Iron Works, Oldham.

1882. Taylor, Robert Henry, Garfield Lodge, Stoke, Devonport.

1896. Taylor, William Isaac, Messrs. Clarke, Chapman and Co., 50 Fenchurch Street, London, E.C.

1895. Tebbutt, Sidney, 32 Avenue Road, Leamington.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, 17 Victoria Street, Westminster, S.W.

1891. Tetlow, Ernest, Messrs. Tetlow Brothers, Bottoms Iron Works, Hollinwood, near Manchester.

1877. Thom, William, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1889. Thomas, James Donnithorne, 25A Old Broad Street, London, E.C. [*Kooringa, London.*]

1896. Thomas, James Martin, Superintending Engineer, Boston and Dominion Lines of Steamers; 24 James Street, Liverpool.

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1897. Thomas, Lewis Richard, Great Western Railway Works, Swindon; and Eastcourt Lodge, Swindon.

1888. Thomas, Philip Alexander, 35 Queen Victoria Street, London, E.C. [*Argument, London.*]

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 6 Delahay Street, Westminster, S.W.

1891. Thompson, James, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1875. Thompson, John, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1875. Thomson, James McIntyre, Glen Tower, Great Western Road, Glasgow.

1868. Thomson, John, 3 Crown Terrace, Dowanhill, Glasgow.

1889. Thomson, Robert McNider, Kobe Engine Works, Kobe, Japan: (or care of William Hipwell, Hillside House, Sharnbrook, Bedford.)

1893. Thornbery, William Henry, 36 Paradise Street, Birmingham. [*Thornbery, Birmingham.*]

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Hull Hydraulic Power Co., Machell Street, Hull.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1876. Thornycroft, John Isaac, F.R.S., Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Engineer, New South Wales Government Railways, Eveleigh Workshops, Sydney, New South Wales: (or care of Joseph Meilbek, 13 Victoria Street, Westminster, S.W.)

1896. Tickner, Richard, 60 Mintern Street, New North Road, London, N.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium. [*Société Meuse, Liége.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1890. Titley, Arthur, Beechwood, Hartopp Road, Four Oaks, Sutton Coldfield, near Birmingham.

1888. Todd, Robert Ernest, Mechanical Engineer, Tucuman, Estacion Provincia, Argentine Republic: (or care of William H. Todd, County Buildings, Land of Green Ginger, Hull.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and 28 Victoria Street, Westminster, S.W.

1896. Toone, William Carson, Messrs. Carson and Toone, Wiltshire Foundry, Warminster.

1888. Topple, Charles James, 6 Blendon Terrace, Plumstead Common.

1894. Touch, John Edward, 16 Fore Street Avenue, London, E.C.

1883. Tower, Beauchamp, 5 Queen Anne's Gate, Westminster, S.W.

1889. Towler, Alfred, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1893. Townsend, Major C. Collingwood, R.A., Superintendent, Gun-Carriage Factory, Madras, India.

1890. Trail, John, Marine Superintendent, Knott's Prince Line of Steamers, Newcastle-on-Tyne.

1888. Travis, Henry, Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1889. Treharne, Gwilym Alexander, Pontypridd; and Aberdare.

1889. Trenery, William Penrose, Poste Restante, Paris.

1883. Trentham, William Henry, 39 Victoria Street, Westminster, S.W.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1896. Trotter, Alexander Pelham, Government Electrician to Cape Colony, Cape Town, Cape Colony.

1885. Trueman, Thomas Brynalyn, 3 The Barons, Twickenham.

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Bishopbriggs, Glasgow. [*Valve, Glasgow.* 1270.]

1885. Turnbull, John, Jun., 18 Blythswood Square, Glasgow. [*Turbine, Glasgow.* 59.]

1894. Turner, Albert, Whitehouse Machine Works, Denton, near Manchester. [*Machines, Denton.* 5.]

1897. Turner, Alfred, Works Manager, Messrs. George Jones, Lionel Street, Birmingham.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1882. Turner, Thomas, Messrs. Andrew Barclay, Sons and Co., Caledonia Works, Kilmarnock. [*Barclayson, Kilmarnock.* 10.]

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1897. Twelvetrees, Walter Noble, Messrs. Harper Twelvetrees, 122 Southwark Street, London, S.E.; and 91 Louisville Road, Tooting, London, S.W.

1856. Tyler, Sir Henry Whatley, K.C.B., Linden House, Highgate Road, London, N.W.

1875. Urquhart, Thomas, Delny House, Delny, R.S.O., Ross-shire.

1880. Valon, William Andrew McIntosh, 140 and 141 Temple Chambers, Temple Avenue, London, E.C.; and Ramsgate. [*Valon, Ramsgate.*]

1895. Van Raalte, Joseph, General Manager, Royal Shipbuilding and Engineering Works, Flushing, Holland. [*Schelde, Flushing.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Vaunting, Manchester.* 5106.]

1897. Vaux, Walter, General Manager, Bradford Tramways and Omnibus Co., Northgate, Bradford. [*Omnibus, Bradford.*]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]

1889. Vesian, John Stuart Ellis de, 20 New Bridge Street, Blackfriars, London, E.C. [*Biceps, London.*]

1891. Vicars, John, Gillbank, Boot, viâ Carnforth.

1865. Vickers, Albert, Messrs. Vickers Sons and Maxim, River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs Vickers Sons and Maxim, River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, The Hon. Nowrosjee Nesserwanjee, C.I.E., Messrs. Nowrosjee Wadia and Sons, Tardeo, Bombay: Bella Vista, Cumballa Hill, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Bombay.*]

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1888. Waister, William Henry, Locomotive and Carriage Running Department, Great Western Railway, Swindon.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, 123 Rathgar Road, Dublin.

1892. Waldron, Patrick Lawrence, R.N.R., Rockville Cottage, Castletown Berehaven, Co. Cork, Ireland; and 24 St. Joseph's Road, Aughrim Street, Dublin.

1890. Walkeden, George Henry, Proprietary Mine, Broken Hill, New South Wales.

1891. Walker, Arthur Tannett, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1890. Walker, Henry, 11 Oxford Terrace, Gateshead.

1894. Walker, Henry Claude, Messrs. R. Waygood and Co., Falmouth Road, Great Dover Street, London, S.E. [*Waygood, London.* 4760.]

1875. Walker, John Scarisbrick, Messrs. Walker Brothers, Pagefield Iron Works, Wigan; and 41 Leyland Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Sydney Ferris, Cardiff Electrical Works, Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Hunter's Forge, New Bridge Street, Newcastle-on-Tyne. [*Dynamo, Newcastle-on-Tyne.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1890. Walker, William George, 47 Victoria Street, Westminster, S.W.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1897. Wall, Charles Henry, General Manager, Belle Vale Steel Tube Works, Halesowen, Birmingham.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1895. Wallace, Joseph, Tennant's Agency, San Fernando, Trinidad.

1884. Wallau, Frederick Peter, Superintendent Engineer, Union Steam Ship Co., Southampton.

1868. Wallis, Herbert, 239 Drummond Street, Montreal, Canada.

1893. Wallwork, Roughsedge, Union Bridge Iron Works, Charter Street, Manchester.

1891. Walmsley, John, Messrs. J. and P. Coats, Ferguslie Thread Works, Paisley.

1865. Walpole, Thomas, Windsor Lodge, Monkstown, Co. Dublin.

1877. Walton, James, 9 Heathwood Gardens, Old Charlton, Kent.

1881. Warburton, John Seaton, 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, 22 Ampthill Road, Bedford.

1876. Ward, William Meese, Newton Villa, Claremont Road, Handsworth, R.O., near Birmingham.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, R.O., near Birmingham. [*Bolts, Birmingham.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.

1885. Warren, Henry John, Jun., Cornwall Boiler Works, Camborne.

1885. Warren, William, Chief Engineer, Midland Uruguay Railway, Paysandu, Uruguay: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1897. Warren, William, Works Manager, Southwick Engine Works, near Sunderland.

1889. Warsop, Thomas, Coniston Copper Mines, Coniston, S.O., Lancashire.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1891. Waterous, Julius E., Waterous Wire Nail Works, Brantford, Ontario, Canada.

1881. Watkins, Alfred, 58 Fenchurch Street, London, E.C.

1862. Watkins, Richard, 18 Cambridge Gardens, Hastings.

1890. Watkinson, William Henry, Professor of Motive Power Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1890. Watson, George Coghlan, Manganese Bronze and Brass Co., St. George's Wharf, Deptford, London, S.E.; and Granville House, Bedford Park, Croydon.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1896. Watson, James Falshaw, 15 Shaw Lane, Headingley, Leeds. [*Inspection, Leeds.*]

1897. Watson, John B., 25 Grantly Gardens, Shawlands, Glasgow.

1897. Watson, Thomas John, 32 Grainger Street West, Newcastle-on-Tyne.

1879. Watson, Sir William Renny, 16 Woodlands Terrace, Glasgow.

1877. Watts, John, 8 Nelson Street, Bristol.

1897. Wearing, John Evenden, Swan Buildings, Edmund Street, Birmingham.

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1894. Webb, Henry, Messrs. Joseph Webb and Co., Irwell Forge and Rolling Mills, Bury, Lancashire.

1884. Webb, Richard George, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India: (or care of Messrs. Richardson and Hewett, 101 Leadenhall Street, London, E.C.)

1890. Webster, John James, 39 Victoria Street, Westminster, S.W.

1887. Webster, William, 6 Oxley Road, Singapore, Straits Settlements.

1891. Weightman, Walter James, Engineer-in-Chief, Nilgiri Railway, Coonoor, Madras, India.

1888. Wellman, Samuel T., Wellman Seaver Engineering Co., New England Building, Cleveland, Ohio, United States.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokyo, Japan.

1895. West, Charles Herbert, Messrs. Henry H. West and Son, 5 Castle Street, Liverpool. [*Referee, Liverpool.* 5223.]

1876. West, Henry Hartley, Messrs. Henry H. West and Son, 5 Castle Street, Liverpool. [*Referee, Liverpool.* 5223.]

1894. West, James, P.O. Box 3010, Johannesburg, Transvaal, South Africa.

1894. West, John, Albion Iron Works, Miles Platting, Manchester.

1891. West, Leonard, Ravenhead Plate Glass Works, St. Helen's, Lancashire.

1874. West, Nicholas James, Trevales Mansion, St. Stythians, Perranarworthal, Cornwall.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* 3199.]

1877. Western, Maximilian Richard, care of Colonel Western, C.M.G., Broadway Chambers, Westminster, S.W.

1895. Westmacott, Henry Armstrong, Messrs. John Spencer and Sons, Newburn Steel Works, Newcastle-on-Tyne.

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong, Whitworth and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1880. Westwood, Joseph, Barkway, Herts.

1888. Weyman, James Edwardes, 38 Derby Street, Moss Side, Manchester.

1896. Wheeler, Percy, General Manager, Oldbury Railway-Carriage and Wagon Works, Oldbury, near Birmingham. [*Carriage Co., Oldbury.*]

1894. Whitby, Arthur George, The Limes, Amersham.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, 25 Bucklersbury, London, E.C.

1888. White, Sir William Henry, K.C.B., LL.D., D.Sc., F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

1890. Whitehouse, Edwin Edward Joseph, Monkbridge Iron Works, Leeds.

1876. Whiteley, William, Holly Mount, Edgerton, Huddersfield.

1891. Whittaker, John, Messrs. William Whittaker and Sons, Sun Iron Works, Oldham.

1897. Whittell, Alfred Leighton, Manager, Union Cotton Mills, Delisle Road, Parel, Bombay, India.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1878. Whytehead, Hugh Edward, Meadowside, Mayfield Road, Moseley, Birmingham.

1878. Wicks, Henry, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of John Spencer, 121 West George Street, Glasgow.)

1897. Wicksteed, Charles, Stamford Road Works, Kettering.

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1891. Widdowson, John Henry, Britannia Works, Ordsal Lane, Salford, Manchester. [*Taps, Salford.*]

1897. Widdowson, John Henry, Jun., Britannia Works, Ordsal Lane, Salford, Manchester; and 11 Meadow Street, Moss Lane West, Manchester. [*Taps, Salford.*]

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1889. Wigham, John Richardson, Messrs. Edmundsons, Stafford Works, 35 Capel Street, Dublin.

1881. Wigzell, Eustace Ernest, Billiter House, Billiter Street, London, E.C. [*Wigzell, London.* 1844.]

1886. Wildridge, John, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales: (or care of R. Wildridge, 7 Alexandra Crescent, Newcastle-on-Tyne.)

1890. Wildy, William Lawrence, 32 Petherton Road, Highbury New Park, London, N.

1892. Wilkinson, Edward R., Ellerton Lodge, Church End, Finchley, London, N.

1893. Williams, Arthur Edward, Resident Engineer, Dagenham Dock, Essex.

1883. Williams, Sir Edward Leader, Engineer, Manchester Ship Canal Co., 41 Spring Gardens, Manchester [*Leader, Manchester.* 688.]; and The Oaks, Altrincham.

1884. Williams, John Begby, Central Marine Engine Works, West Hartlepool.

1885. Williams, Nicholas Thomas, 43 Threadneedle Street, London, E.C.

1847. Williams, Richard (*Life Member*), Brunswick House, Wednesbury.

1890. Williams, Thomas David, 16 Lancaster Road, South Norwood, London, S.E.

1881. Williams, William Freke Maxwell, 29 Great St. Helen's, London, E.C. [*Wabash, London.*]

1873. Williams, William Lawrence, 16 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1889. Williams, William Walton, Jun., 87 Elspeth Road, New Wandsworth, London, S.W.

1897. Williams, Wyndham Henry, Messrs. Arthur Butler and Co., Mozufferpore, Tirhoot, India.

1896. Williamson, Joseph, São Paulo Railway, São Paulo, Brazil.

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington; and South Lodge, Cockermouth.

1897. Wills, Frank, Messrs. W. and F. Wills, Perseverance Works, Bridgwater.

1878. Wilson, Sir Alexander, Bart., Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1884. Wilson, James, Pacha, Chief Engineer of the Daira Sanieh, Egypt: Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, 39 Victoria Street, Westminster, S.W.

1892. Wilson, John Charles Grant, Locomotive Superintendent, Manila Railway, Manila, Philippine Islands.

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1890. Wilson, Joseph William, Jun., Vice-Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1880. Wilson, Robert, 10 St. Bride Street, London, E.C.; and 7 St. Andrew's Place, Regent's Park, London, N.W.

1883. Wilson, Robert, F.R.S.E., 13 Victoria Street, Westminster, S.W.

1890. Wilson, Robert James, 24 Rood Lane, London, E.C.

1873. Wilson, Thomas Sipling, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1897. Wilson, William Campbell, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.

1897. Wilson, William Henry, Messrs. W. F. Mason, Longsight, Manchester.

1891. Wimshurst, James Edgar, Messrs. William Esplen, Son, and Swainston, Billiter Buildings, 22 Billiter Street, London, E.C.

1890. Winder, Charles Aston, Messrs. Winder Brothers, Royds Works, Attercliffe, Sheffield.

1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.

1890. Wingfield, Digby Charles, 61 Parliament Hill Road, Hampstead, London, N.W.

1887. Winmill, George, Locomotive and Carriage Superintendent, Oudh and Rohilkund Railway, Lucknow, India: (or Harewood, Junction Road, Romford.)

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 65378.]

1884. Withy, Henry, Messrs. Furness Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]

1878. Wolfe, John Edward, Sunderland and South Shields Water Co., 16 Fawcett Street, Sunderland.

1878. Wolfenden, Robert, Staining, Poulton-le-Fylde, Lancashire.

1888. Wolff, Gustav William, M.P., Messrs. Harland and Wolff, Belfast.

1881. Wood, Edward Malcolm, 3 Victoria Street, Westminster, S.W.

1887. Wood, Henry, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Sir Lindsay, Bart., Southhill, near Chester-le-Street.

1884. Wood, Sidney Prescott, Semaphore Iron Works, Newport, Melbourne, Victoria: (or care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.)

1890. Wood, Thomas Royle, care of Samuel Bash, 1663 Avenida Montes de Oca, Buenos Aires, Argentine Republic: (or care of William Wood, 28 Hyde Grove, Chorlton-on-Medlock, Manchester.)

1896. Wood, Walter Chapman, care of Messrs. J. Buchheister and Co., Shanghai, China.

1890. Wood, William, Gas Meter Co., 238 Kingsland Road, London, E.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1897. Woods, Arthur Robert Thomas, Messrs. James Nelson and Sons, 41 North John Street, Liverpool.

1894. Woods, William Henry, Messrs. Hamilton Woods and Co., Liver Foundry and Engine Works, Ordsal Lane, Salford, Manchester. [*Sluice, Manchester.* 1962.]

1895. Wordingham, Charles Henry, Electric Light Station, Dickinson Street, Manchester.

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1874. Worsdell, Thomas William, Stonycroft, Arnside, near Carnforth.

1894. Worsdell, Wilson, Locomotive Superintendent, North Eastern Railway, Gateshead.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)

1888. Worthington, Edgar, 19 Victoria Street, Westminster, S.W.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and Mill Bank, Bowdon, near Altrincham.

1897. Worthington, William Barton, Chief Engineer, Lancashire and Yorkshire Railway, Manchester.

1881. Wrench, John Mervyn, Chief Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.

1897. Wright, Frederick George, Great Western Railway Works, Swindon.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., 181 Queen Victoria Street, London, E.C.

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and The Gresham Club, London, E.C.

1895. Wright, William, 16 Great George Street, Westminster, S.W.; and Dudley House, 10 St. John's Hill Grove, New Wandsworth, London, S.W.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1891. Wroe, Joseph, 26 Park Avenue, Manchester, S.E.

1895. Wylie, John Condie, St. Ives, Cornwall; or care of the Royal Colonial Institute, Northumberland Avenue, London, W.C.

1865. Wyllie, Andrew, 1 Leicester Street, Southport.
1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.

1889. Yarrow, Alfred Fernandez, Isle of Dogs, Poplar, London, E.
1895. Yarwood, William James, Castle Dock Yard, Northwich. [74.]
1881. Yates, Louis Edmund Hasselts, District Locomotive and Carriage Superintendent, Eastern Bengal State Railway, Saidpore, Bengal, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)
1880. York, Francis Colin, Locomotive Superintendent, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of W. Hannay, 18 Portland Street, Leamington.)
1889. Young, David, 11 and 12 Southampton Buildings, London, W.C. [*Junkring, London.*]
1879. Young, George Scholey, Engineer, Thames Iron Works, Orchard Yard, Blackwall, London, E.
1874. Young, James, 19 Wentworth Place, Newcastle-on-Tyne.
1892. Young, Robert, Engineer and Manager, Penang Steam Tramways, Penang, Straits Settlements.
1894. Young, Smelter Joseph, Messrs. Spear and Jackson, Ætna Works, Savile Street East, Sheffield.
1887. Young, William Andrew, Messrs. Lobnitz and Co., Renfrew, near Paisley [*Lobnitz, Renfrew.* 57, *Paisley.*]; and Millburn House, Renfrew, near Paisley.
1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

ASSOCIATE MEMBERS.

1896. Abady, Jacques, Messrs. Alexander Wright and Co., 81 Page Street Westminster, S.W. [*Precision, London.* 3337.]

1896. Abella, Juan, Director General of Public Lighting, 691 Calle Bolivar, Buenos Aires, Argentine Republic.

1896. Adams, George, 55 Victoria Street, Westminster, S.W.

1892. Adams, Sidney Rickman, Consolidated Gold Fields of South Africa, P.O. Box 67, Johannesburg, Transvaal, South Africa: (or care of Henry Adams, 3 Colville Square, Bayswater, London, W.)

1895. Ahrons, Ernest Leopold, Managing Engineer of Technical School, École Khédiviale d'Arts et Métiers, Cairo, Egypt.

1890. Alderson, George Alexander, Messrs. Allen, Alderson and Co., Alexandria, Egypt; and The Cloisters, Bulkeley, Alexandria, Egypt.

1897. Allen, Justin Edward, Superintendent of Works, Royal Gardens, Kew, Surrey.

1894. Almond, Michael, District Locomotive Inspector, Cape Government Railways, Queenstown, South Africa: (or care of Robert Almond, 21 Hawthorn Road, South Gosforth, Newcastle-on-Tyne.)

1894. Ambler, Frank, Assistant Resident Engineer, Alagoas Railway, Maceio, Brazil.

1897. Appleby, Harry Walton, Messrs. Rosling and Appleby, Trafalgar Works, Bradford. [*Magneto, Bradford.* 844.]

1895. Armstrong, George Edwin, Municipal School of Science and Technology, Richmond Terrace, Brighton.

1897. Arnold, William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1889. Ashford, John, Engineering Department, Northampton Institute, Clerkenwell, London, E.C.

1896. Atkinson, Frederic, Albert Buildings, 49 Queen Victoria Street, London, E.C. [*Fixed, London.*]

1897. Atkinson, Robert Ernest, Messrs. Ashwell and Nesbit, Victoria Foundry, Sycamore Lane, Leicester. [*Plenum, Leicester.* 190.]

1894. Aveline, William Rebotier, Messrs. George Gahagan and Co., Bellasis Road, Byculla, Bombay, India.

1897. Aylesbury, Thomas Antram, London Hydraulic Power Co., 46 Holland Street, Blackfriars Road, London, S.E.; and 37 Kennington Park Road, London, S.E.

1897. Back, Arthur Charles Lemprière, Devon and Cornwall Ice and Cold Storage Co., Plymouth.

1897. Baker, John, Manager, Messrs. Tansley's Ice Works, Lower Fazeley Street, Birmingham.

1897. Baker, Tom William, 6 and 7 Broad Street House, London, E.C.

1897. Ball, John, Geological Survey Office, Public Works Department, Cairo, Egypt.

1897. Bamber, Herbert William, Messrs. Bamber and Lewis, Meopham, Gravesend.

1896. Barba, Alfonso G., Messrs. J. and G. Thomson, Clydebank, Glasgow; and Marie Place, 35 Crow Road, Partick, Glasgow.

1896. Barker, Arthur Henry, 62 Alderney Street, Eccleston Square, London, S.W.

1893. Barker, Frederic William, 33A Hammersmith Broadway, London, W. [*Barker, Broadway, Hammersmith.*]; and 28 Prebend Gardens, Chiswick, London, W.

1894. Baron, Francis Edward, Great Horseless Carriage Co., Motor Mills, Coventry.

1896. Baron, James Thomas, Resident Engineer, St. Pancras Electricity and Public Lighting Department, 47 Stanhope Street, London, N.W.

1896. Barton, Andrew, Admiralty, 21 Craven Street, Strand, London, W.C.

1893. Beazley, Ernest, care of Messrs. Antonio Giorgi and Co., Funchal, Madeira.

1897.*Beck, John, European Petroleum Co., Balachany, near Baku, Russia: (or care of Miss Kendall, 67 Dorchester Road, Weymouth.)

1897. Beckton, William Rushworth, Chief Engineer, Hotel Cecil, Strand, London, W.C.

1897. Bedbrook, James Albert Harvey, care of Messrs. R. and W. Hawthorn, Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1890. Bell, William Thomas, Mulgrave, St. Catherine's, Lincoln.

1895. Bennis, Alfred William, Messrs. E. Bennis and Co., Lancashire Stoker Works, Deansgate Foundry, Bolton.

1896. Bentley, Wallace, Royal Insurance Buildings, Crossley Street, Halifax.

1893. Bishop, Henry, 38 Gresham Street, Lincoln.

1897. Blakiston, Ralph, Superintending Engineer, Palatine Engineering Co., 10 Blackstock Street, Liverpool; and Waterloo, Liverpool.

1895. Blaxter, Augustus Pearce, Jun., Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N.

1896. Blumfield, Thomas William, 22 Strensham Road, Balsall Heath, Birmingham.

1896. Bosley, Walter Joseph, Resident Engineer, Guildford Main Drainage Outfall Works, Stoke-by-Guildford.

1895. Boulden, Frederick, Technical Department, University College, St. George's Square, Sheffield.

1897. Bradley, James William, Town Hall, Wolverhampton.

1896. Bremner-Davis, William Joseph, 24 Parkfield Street, Whitworth Park, Manchester.

1895. Bruce, Robert Arthur, Brennan Torpedo Factory, Chatham.

1892. Bulwer, Ernest Henry Earle, Linde British Refrigeration Co., 35 Queen Victoria Street, London, E.C.

1893. Burden, Alfred George, Messrs. Tangyes, P. O. Box 818, Johannesburg, Transvaal, South Africa: (or care of George N. Burden, Oakfield, Teignmouth.)

1895. Burn, George Francis, The Technical School, Cookridge Street, Leeds.

1890. Burne, Edward Lancaster, Messrs. Dickinson and Burne, Church Acre Iron Works, Guildford.

1897. Burnside, Bertram W., Horsell, Woking.

1896. Butcher, Malcolm Henry, Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1891. Buttenshaw, George Eskholme, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1896. Carolin, Edward Marlay, P. O. Box 80, Bloemfontein, Orange Free State, South Africa.

1895. Carver, Charles Frederick, Alfred Street Machine Works, Nottingham. [*Carver, Nottingham.*]

1897. Cerrito, Frank Henry, 71 Temple Row, Birmingham. [*Cerrito, Birmingham.*]

1895. Challenger, Godfrey Richard, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1896. Clare, Ernest, Messrs. Arnold Goodwin and Son, Sumner Street, Southwark, London, S.E.

1894. Clark, James Lester, Messrs. Clark and Aiton, 102 Fenchurch Street, London, E.C. [*Channeled, London.*]

1895. Clatworthy, Walter Angove, 29 Lily Avenue, Jesmond, Newcastle-on-Tyne.

1897. Clegg, John Henry, Lower Lumb Mill, Heptonstall, Manchester.

1896. Comerford, Edward, Laragh, Victoria Park, Wavertree, Liverpool.

1897. Connell, William Percival, Calle Sanz 14, Minas de Rio Tinto, Huelva, Spain: (or care of W. G. Connell, 83 Cheapside, London, E.C.)

1896. Conradi, Julius Samuel, Messrs. John I. Thornycroft and Co., Church Wharf, Chiswick, London, W.

1896. Cooper, Thomas, Cox Thermo Electric Co., St. Albans; and Spring Valley, Beaconsfield Road, St. Albans.

1895. Corby, Matthew, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield; and 160 Hagley Road, Birmingham.
1893. Corkhill, William, Manager, Shalimar Engineering and Shipbuilding Works, Calcutta, India.
1894. Coventry, Theodore, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester. [*Gresley, Manchester.* 564.]
1893. Cowell, John Ray, P.O. Box 2141, Johannesburg, Transvaal, South Africa.
1895. Cowie, William, Lidgerwood Manufacturing Co., Soerabaya, Java.
1896. Cox, Edward Henry, De la Vergne Refrigerating Machine Co., Foot of East 138th Street, New York, United States.
1897. Craig, Alexander, Messrs. Humber and Co., Coventry.
1897. Crooke, Walter, Jun., Frodingham, near Doncaster.
1887. Crosland, Delevante William, 22 Royal Crescent, Kensington, London, W.
1895. Cust, Leopold, Gas Traction Co., 22 Chancery Lane, London, E.C.; and 99 Onslow Square, London, S.W.

1894. Dadina, Hormuz Minocher, Consulting Engineer, Khetwady, Bombay, India.
1894. Davey, Edward Ernest George, 15 Westmoreland Street, Marylebone, London, W.
1896. Davidson, John McKenzie, General Contractor, Karachi, India.
1896. Davis, Francis Myddleton, Works Manager, Messrs. R. and T. Elworthy, Elizabethgrad, Russia.
1897. Davy, David, Jun., Messrs. Davy Brothers, Park Iron Works, Sheffield. [*Motor, Sheffield.*]
1896. Dawson, Philip, 39 Victoria Street, Westminster, S.W.
1890. Day, Arthur Godfrey, Director of Studies, Science Art and Technical Schools, Guildhall, Bath.
1894. Dickinson, Harold, Central Electric Lighting Station, Yorkshire House to House Electricity Co., Whitehall Road, Leeds. [*Electricity, Leeds.* 1013.]
1896. Dossor, Herbert, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.
1891. Douglass, Alfred Edwards, South Staffordshire Water Works, Paradise Street, Birmingham.
1896. Dowson, Erasmus Charles Head, Lattendales, Penrith.
1895. Dronsfield, James, Messrs. Dronsfield Brothers, Atlas Works, Oldham.
1895. Dumas, Robert, Messrs. Siemens Brothers and Co., Woolwich.
1895. Duncan, William, Locomotive Department, Cape Government Railways, Uitenhage, Cape Colony.
1894. Dunolly, Alan, Farley, Reigate.

1894. Eastmead, Frederic James, Messrs. Moffatt and Eastmead, 39 Victoria Street, Westminster, S.W. [*Hoistway, London.*]

1892. Edgcome, James Edmund, Resident Engineer, Electric Light Station, Kingston-on-Thames.

1893. Edmondson, Alfred Richard, The Oaks, Moss Lane, Timperley, Altrincham.

1891. Edwards, Herbert Francis, Messrs. Forster Brown and Rees, Guildhall Chambers, Cardiff.

1897. Epton, William Martin, P.O. Box 1607, Johannesburg, Transvaal, South Africa.

1895. Fawcett, Percy William, Whirlow Court, Sheffield.

1894. Fendick, Walter, Gas Works, Hemel Hempstead.

1896. Fforde, William John, 2 Glenview Terrace, Springfield Road, Belfast.

1894. Finlayson, David, Burnhead, Larbert, Stirlingshire.

1896. Firth, John, 25 Jowett Street, South Reddish, Stockport.

1894. Fitz-Gerald, John Frederick Gerald, care of El Señor Ingeniero, Departamento de Vias y Obras F.C.S., Buenos Aires, Argentine Republic.

1895. Fleischer, Paul, Messrs. A. Guinness, Son and Co., St. James' Gate Brewery, Dublin.

1892. Fletcher, Joseph Ernst, Messrs. Charles Cammell and Co., Cyclops Works, Sheffield.

1895. Forbes, George Chichester, Locomotive Department, South Indian Railway, Negapatam, India.

1895. Foster, Edward Hornby, Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1896. Fraser, Frank Hazell, Messrs. W. J. Fraser and Co., 98 Commercial Road East, London, E. [*Fraser, Engineer, London.* 4413.]

1897. Frerichs, Jacob Andrew, Construction Department, East Rand Proprietary Mines, Boksburg, Transvaal, South Africa.

1897. Furness, Charles, Messrs. Veale and Co., 79 Old Town Street, Plymouth.

1896. Gallé, William Alexandre, Locomotive Department, Great Central Railway, Gorton, Manchester.

1896. Garratt, Herbert Alfred, Northern Polytechnic Institute, Holloway Road, London, N.

1896. Garratt, James Herbert, Messrs. Whittall and Co., Colombo, Ceylon.

1896. Garrett, Easton, Messrs. Bailey, Walker and Co., 456 Calle Cuyo, Buenos Aires, Argentine Republic.

1890. Garrett, Frank, Jun., Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.

1896. Given, Ernest Cranston, Messrs. Priestman and Co., Philadelphia, Pennsylvania, United States; and The Lodge, Aigburth, Liverpool.

1896. Goffe, Edward, De Beer's Consolidated Mines, Kimberley, South Africa.

1897. Gordon, John Wilton, Messrs. John Gordon and Co., Dashwood House, 9 New Broad Street, London, E.C.

1897. Grant, Hector, Messrs. George Smith and Co., Sun Foundry, Glasgow and Clippens, 104 Maxwell Street, Glasgow.

1896. Grant, William, care of A. Basil Wilson, Martello Terrace, Holywood, Belfast.

1896. Gray, Alexander Cuthill, Assistant Locomotive Superintendent, Rio Grande do Sol Railway, Rio Grande do Sol, Brazil.

1895. Greene, William Spencer Clayton, 33 Norfolk Street, Strand, London, W.C.; and 47 Edwardes Square, London, W. [*Shipworm, London.*]

1893. Gritton, Joseph, 8 Lumley Road, Chester.

1895. Groundwater, Samuel, Messrs. S. C. Farnham and Co., Old Dock, Shanghai, China.

1897. Grove, Harry, Messrs. Willey and Co., Exeter.

1895. Groves, Montague, Moore's Rhodesia Concession, Salisbury, Mashonaland, South Africa.

1894. Hadengue, Charles Benjamin, Messrs. Carew and Co., Rosa Sugar Works, Rosa, North Western Provinces, India.

1895. Haines, Charles James, Southampton Water Works, Otterbourne, near Winchester.

1896. Hall, Benjamin James, 39 Victoria Street, Westminster, S.W.

1894. Hall, Robert Frederick, Ferndale, Church Road, Moseley, Birmingham.

1897. Halsey, Charles Turner, care of Samuel Puplett, 47 Victoria Street, Westminster, S.W.; and Womersley House, Crouch Hill, London, N.

1894. Hardy, William, Woodview, Bessbrook, County Armagh, Ireland.

1897. Harlow, Bernhard Schäffer, Messrs. Robert Harlow and Son, Heaton Norris Brass Works, Stockport.

1894. Harris, Herbert Nelson, St. Michael's Foundry, Bridport.

1897. Harwood, Robert Henry, Howrah Jute Mills, Seebpore, Calcutta, India.

1896. Hawes, David Marc Andrew Graham, 19 and 21 Queen Victoria Street, London, E.C.

1897. Hawes, William Fox, Jun., Messrs. Kincaid, Waller and Manville, 29 Great George Street, Westminster, S.W.

1897. Hawkins, Thomas Spear, St. John del Rey Mining Co., Morro Velho, Brazil.

1896. Heath, Charles Lewis Eclair, Municipal Technical School, 86 Osborne Street, Hull.

1897. Hemingway, Alfred, Great Southern Railway, Albany, Western Australia.

1894. Henderson, Arthur James, 15 and 16 Giltspur Street, London, E.C. [*Henfish, London.*]

1896. Hill, Thomas, Spoutmouth, Gallowgate, Glasgow. [*Specify, Glasgow.* 4758.]

1897. Hill, Walter Charles, 48 Heathwood Gardens, Little Heath, Charlton, Kent.

1895. Hockley, Norman Julius, Seaton, Devonshire.

1897. Hodges, Frank William, Messrs. Thomas Cook and Son, Boulac Engine Works, Cairo, Egypt; and Tullgarn, 37 Cromwell Road, West Brighton, Brighton.

1896. Hollingsworth, Edward Massey, Corporation Gas Works, Warrington Old Road, St. Helen's, Lancashire.

1895. Horner, Joseph Gregory, 17 Vernon Terrace, Twerton-on-Avon, Bath.

1895. House, Henry A., Jun., Manager, Liquid Fuel Engineering Co., Columbine Ship Yard, East Cowes, Isle of Wight.

1894. Hyde, George Herbert (*Life Associate Member*), Managing Engineer, Colombo Commercial Co., Colombo, Ceylon.

1896. Iden, George, Motor Mills, Coventry.

1895. Ingham, William, Water Engineer, Torquay.

1897. Ironside, William Allan, Messrs. Ironside, Son and Co., 1 Gresham Buildings, Guildhall, London, E.C. [*Ironside, London.*]

1897. Irvine, Archibald John, P.O. Box 149, Johannesburg, Transvaal, South Africa.

1896. Issigonis, George Demos, The D. Issigonis Works, Smyrna, Turkey in Asia.

1893. Jenkin, Charles James, Council Offices, Willenhall, Wolverhampton.

1897. Johns, Cosmo, Messrs. Vickers, Sons and Maxim, River Don Works, Sheffield.

1896. Johnson, Andrew, 120 Nithsdale Road, Glasgow.

1897. Johnson, George, P.O. Box 2029, Johannesburg, Transvaal, South Africa.

1896. Jones, Thomas Gilbert, The Technical School, Mount Pleasant, Swansea.

1889. Joy, Basil Humbert, 85 Gracechurch Street, London, E.C.; and 118 Broadhurst Gardens, West Hampstead, London, N.W.

1895. Kennedy, Robert Baird, Fish Dock Road, Grimsby.

1896. Kerr, Alfred Ernest Campbell (*Life Associate Member*), The School of Mines, Ballarat, Victoria.

1893. Kershaw, Thomas, Technical School, Huddersfield.

1894. Kerslake, Walter Edmund, 16 Woodland Road, Walton, Liverpool.

1897. Ketley, Charles Bosworth, 128 Colmore Row, Birmingham. [*Invent, Birmingham.* 1132.]

1897. King, Andrew, 361 Lenton Boulevard, Nottingham.

1893. Kirk, Percy Roebuck, 5 Lyncroft Mansions, West End Lane, London, N.W.

1897. Lacy-Hulbert, Charles Edward, 17 Avenue Louise, Brussels, Belgium. [*Hulbert, Bruxelles.* 1384.]

1895. Larard, Charles Edward, Battersea Polytechnic Institute, Battersea, London, S.W.

1897. Larmuth, John Hamilton, Messrs. Thomas Larmuth and Co., Todleben Iron Works, Unwin Street, Cross Lane, Salford, Manchester; and 452 Eccles New Road, Weaste, near Manchester.

1896. Lawson, Harry John, 40 Holborn Viaduct, London, E.C.

1893. Lea, Arthur Henry, Messrs. Lea and Warren, Kettering.

1897. Leitch, Archibald, 40 St. Enoch Square, Glasgow. [*Tracing, Glasgow.* 5197.]

1895. Longbottom, John Gordon, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1896. Lovell, Samuel George, 73 The Crescent, South Tottenham, London, N.

1897. MacIvor, Alexander, Messrs. Potter and Co., Hollins Paper Mills, Darwen.

1896. Malloch, William Farquhar, P.O. Box 2681, Johannesburg, Transvaal, South Africa.

1896. Mansfield, Alfred, Manager, Messrs. P. Orr and Sons, Mount Road, Madras, India.

1894. Mansfield, Edwin Albert, Moorgate Station Chambers, London, E.C. [*Indiarsi, London.*]

1897. Mansfield, Walter, Messrs. Edwin Mansfield and Sons, Whitby Engineering Works, near Chester. [*Mansfield, Whitby, Chester.*]

1893. Manton, Arthur Woodroffe, Central London Railway, 7 Holland Park Avenue, London, W.

1896. Martin, George Best, Works Manager, British Tube Co., Cornwall Road, Smethwick, Birmingham.

1895. Massey, Leonard Fletcher, Messrs. B. and S. Massey, Openshaw, Manchester. [*Masseys, Openshaw.* 300.]

1896. McCormack, William John, 29 Bow Lane, Cannon Street, London, E.C.

1894. McGeorge, James, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India.

1891. McMeekin, Adam, Cogry Flax Spinning Mills, Doagh R.S.O., Co. Antrim, Ireland.

1897. Meggitt, George Teale, Messrs. Samuel Meggitt and Sons, Hamilton Road, Sutton-in-Ashfield, Nottingham.

1895. Messer, Edgar Harrisson, P.O. Box 1940, Johannesburg, Transvaal, South Africa: (or care of John Messer, Danbury, Alexandra Road, Reading.)

1894. Mills, Arthur Edwin, 4 Victoria Terrace, Clifton, Bristol.

1897. Mills, Samuel James Augustus, Belgrave Mills, Darwen.

1893. Mitchell, James Frederick Bruce, Messrs. J. F. B. Mitchell and Co., Mazagon Iron Works, Bombay, India.

1896. Mitton, Thomas Evans, Messrs. Hunt and Mitton, Crown Brass Works, Oozells Street North, Birmingham. [*Mitton, Birmingham.* 394.]

1894. Monckton, Charles John, Phoolultah Tea Estate, Sagurnal Post Office, Sylhet, Assam, India.

1896. Moncrieff, Robert Wighton, The Grange, Stoke Goldington, Newport Pagnel.

1895. Moore, Thomas Lamb, Messrs. James Moore and Sons, Millfield Foundry, Belfast. [*Moore, Millfield, Belfast.* 466.]

1897. Moule, Frederick Oswald, Messrs. Ruston, Proctor and Co., Sheaf Iron Works, Lincoln.

1893. Mountain, Benjamin, South Parade, Leeds.

1895. Mount-Haes, Andrew, Standard Weldless Tube and Cycle Components, Wharf Street, Aston, Birmingham.

1893. Moylan, William Morgan, care of Messrs. Grindlay and Co., Calcutta, India.

1894. Murphy, Edward Owen, R.N.R., Chief Engineer, R.M.S. "Empress of Japan," Vancouver, British Columbia.

1897. Nakagawa, Goeokichi, Chief Engineer, Tokyo Gas Co., Tokyo, Japan.

1895. Nesbit, David Mein, Messrs. Ashwell and Nesbit, 12 Great James Street, Bedford Row, London, W.C. [*Plenum, London.* Holborn, 587]; and Victoria Foundry, Leicester.

1896. New, Alfred Wilmot, Messrs. D. New and Co., 31 Devonshire Chambers, Bishopsgate Street Without, London, E.C.

1896. New, David James, Messrs. D. New and Co., 31 Devonshire Chambers, Bishopsgate Street Without, London, E.C.

1896. Newell, Ernest, Messrs. Edward Ripley and Sons, Bowling Dye Works, Bradford.

1897. Newman, Reginald William, Messrs. John Aird and Sons, Birmingham Corporation Water Works, Penybont, R.S.O., Radnorshire.

1896. Nicholls, Percy, Oak Villa, Pontefract.

1894. North, Horace, St. George's Engineering Works, Trafalgar Street, Brighton.

1897. Norton, Arthur, 72 Carlyle Road, Edgbaston, Birmingham.

1897. Outram, Francis Davidson, late R.E., 28 Victoria Street, Westminster, S.W.

1897. Page, Henry, 30 Heathcote Street, Nottingham.
1897. Parish, Charles Edward, Ouston Collieries, Chester-le-Street, Co. Durham.
1896. Parker, John, Messrs. E. Green and Son, 2 Exchange Street, Manchester.
1896. Patel, Motibhai Bhikhabhai, Bhadran, near Borsad, India.
1896. Patel, Raojibhai Motibhai, Principal, Kala-Bhavan, Baroda, India.
1893. Paterson, Robert Mair, 78 Broadhurst Gardens, Hampstead, London, N.W.
1896. Pendred, Loughnan St. Lawrence, 33 Norfolk Street, Strand, London, W.C.
1895. Penn, William Cooper, 15 Victoria Street, Westminster, S.W. [*Penniform, London.* 3075.]
1893. Pertwee, Herbert Arthur, Messrs. Elliott's Metal Co., Pembrey Copper Works, Burry Port, R.S.O., Carmarthenshire.
1897. Phillips, Edwin Grant, Messrs. Sturgess and Foley, 52 Calle de Alcala, Madrid, Spain.
1895. Phillips, Exham, Crescent Iron Works, Salford, Manchester; and Rostellan, Worsley, Manchester.
1897. Pickles, John Edward, Municipal Technical School, Birmingham.
1897. Pilling, Henry, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.
1891. Pirrie, John Barbour, Barn Flax Spinning Mills, Carrickfergus, Co. Antrim, Ireland.
1897. Player, Ralph, Messrs. Joseph Wright and Co., Neptune Works, Tipton.
1896. Pollard, Ferdinand Joseph, P.O. Box 2485, Johannesburg, Transvaal, South Africa.
1897. Porter, Stanley William, Paragon Chambers, Hull.
1895. Powell, Benjamin Newton, Manager, Lidgerwood Manufacturing Co., Soerabaya, Java: (or care of C. T. Powell, Cherry Street, Birmingham.)
1897. Price, Charles Graham, Messrs. Samuel, Samuel and Co., Yokohama, Japan.
1887. Price-Williams, John Morgan, 28 Compayne Gardens, West Hampstead, London, N.W.
1896. Pritchard, Hugh, Dinorwic Slate Quarries, Llanberis, near Carnarvon; and 14 Terfyn Terrace, Port Dinorwic, near Bangor.
1895. Pugh, Charles Vernon, 34 Spon Street, Coventry.
1895. Pullar, Albert Evans, Pullar's Dye Works, Perth.

1894. Raleigh, Charles, 58 Chancery Lane, London, W.C.
1896. Rayner, Harry Stafford, Dowson Economic Gas and Power Co., 39 Old Queen Street, Westminster, S.W.; and Seneca, Fanthorpe Terrace, Erpingham Road, Putney, London, S.W.
1892. Redfern, Charles George, 4 South Street, Finsbury, London, E.C.
1893. Richey, William Frederick Albert, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.

1897. Richmond, William Frederick, Longton Iron Works, Staffordshire; and Shellness, Stradella Road, Herne Hill, London, S.E.

1895. Ridley, Clarence Oliver, Sir W. G. Armstrong, Whitworth and Co., 8 Great George Street, Westminster, S.W.

1896. Rieter, E. Henry, Messrs. J. J. Rieter and Co., Winterthur, Switzerland.

1893. Roberts, Charles Thomas, Salisbury, Rhodesia, South Africa.

1897. Rogers, William Ivy, Managing Director, New Merlin Cycle Co., New Summer Street, Birmingham. [*Temptation, Birmingham.* 1817.]

1897. Rolf, George, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne; and 8 Bentinck Crescent, Newcastle-on-Tyne.

1895. Ross, Ernest Sydney, Inspection of Machinery Department, Macquarie Street, Hobart, Tasmania.

1894. Rossiter, James Thomas, Tynwald, Grove Park Road, Chiswick, London, W.

1896. Rothery, William Brockbank, Norbriggs, Lytham, R.S.O., Lancashire.

1894. Rowe, Daniel, care of Mrs. Rowe, Mount Ambrose, Redruth.

1897. Roylance, Arthur Herbert, Haworth's Buildings, 5 Cross Street, Manchester.

1896. Ruffle, Frank Felingham, Messrs. A. J. Bolton and Co., Jackson Ghat Street, Calcutta, India.

1895. Russell, Frederick, Manager, Gas Works, Bexhill-on-Sea.

1897. Ruthen, Charles Tamlin, Bank Chambers, Heathfield Street, Swansea.

1897. Rycroft, John Edward, Engineering Department, Technical College, Bradford.

1894. Salis, Henry Rodolph de, Ivy Lodge, Iver Heath, near Uxbridge.

1896. Samuel, Blelock Lee, Grahamston Foundry and Engine Works, Barrhead, near Glasgow.

1897. Sanders, George, General Manager, Bamboo Cycle Co., Petit Street, Wolverhampton. [*Bamboo, Wolverhampton.*]

1896. Sangster, Charles, Works Manager, Cycle Components Manufacturing Co., Bournbrook, Birmingham.

1896. Scanlan, Horace Edward, Beaconsfield, Longfleet, Poole.

1893. Schloesser, Robert, care of Messrs. Leman and Co., 51 Lincoln's Inn Fields, London, W.C.: (or care of Adolf Schloesser, 185 Sutherland Avenue, London, W.)

1897. Scott, Herbert Kilburn, Usina Wigg, Miguel Burnier, Minas, Brazil.

1897. Scott, Newton L., 55 Schubert Road, Putney, London, S.W.

1897. Scotter, Robert Herbert, 7 Tower Buildings N., Liverpool.

1893. Segundo, Edward Carstensen de, 28 Victoria Street, Westminster, S.W.

1892. Seymour, William Frederick Earl, Engineer's Office, Great Western Railway, Swindon.

1897. Sharpley, George Ruston, Messrs. Ruston, Proctor and Co., Sheaf Iron Works, Lincoln.

1897. Shirtliff, Frederick, Messrs. Temple and Shirtliff, 12 Kentish Town Road, London, N.W.

1897. Sime, William, Messrs. Cook and Co., East London Soap Works, Bow, London, E.

1891. Smith, Joseph Philip Grace, Polytechnic School of Engineering, 309 Regent Street, London, W.

1897. Smith, Sidney, care of Messrs. George Findlay and Co., 21 Adderley Street, Cape Town, Cape Colony.

1894. Smith, William Arthur, Midland Arches, Northampton; and 18 Albion Place, Northampton. [*Machinery, Northampton.*]

1891. Snell, John Francis Cleverton, Borough Electrical Engineer, Corporation Electricity Station, Sunderland.

1897. Spence, John C., Messrs. Thomas Begbie and Co., P.O. Box 1652, Johannesburg, Transvaal, South Africa.

1897. Spencer, Henry Wilmot, Messrs. T. and J. Hosking, Dockhead Iron Works, Parker's Row, Bermondsey, London, S.E.

1896. Stewart, Charles Nigel, 22 and 23 Laurence Pountney Lane, London, E.C.

1896. Stobart, Henry Gervas, Wolsingham Steel Works, Wolsingham, near Darlington.

1897. Stockton, Percy Sadler, The Woodlands, Langley Green, near Birmingham.

1897. Stockwell, Charles Edward, Sydney and Suburban Hydraulic Power Co., Sydney, New South Wales.

1897. Suffield, Frank Wilson, Messrs. Thomas Piggott and Co., Spring Hill, Birmingham; and Glen Lyn, Grove Avenue, Moseley, Birmingham.

1896. Sutherland, James, Manager, Alumina Factory, Larne Harbour, County Antrim, Ireland. [*Aluminium, Larne Harbour.*]

1894. Sutton, Hugh Reginald, Messrs. Mackies, Berks Iron Works, Caversham Road, Reading. [*Mackies, Reading.* 86.]

1896. Swallow, John, Messrs. W. Neill and Son, Bold Iron Works, St. Helen's Junction, Lancashire. [*Neill, St. Helen's.* 20.]

1887. Tabor, Edward Henry, Mill House, Worsley, Manchester.

1893. Takatsuji, Narazo, Superintending Engineer, Calico Weaving Mill, Osaka, Japan.

1895. Takimura, Takeo, General Manager, Osaka Cotton Mill, Osaka, Japan.

1893. Talbot, Frederick William, Engineer and Manager, Water Works, Frimley Green, Farnborough, Hants.

1897. Talbot, William John, General Manager, Messrs. F. A. Harrison, Albion Works, 19 Legge Lane, Birmingham.

1897. Taylor, Arthur Joseph, Yorkshire Boiler Insurance and Steam Users' Co., Sunbridge Chambers, Bradford; and 3 Hallfield Road, Bradford.

1894. Taylor, William, Messrs. Taylor, Taylor, and Hobson, Slate Street Works, Leicester. [*Lenses, Leicester.* 134.]

1893. Tenney, Dennis, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1893. Thomasson, Lucas, Hawkshead House, Hatfield, Herts.

1897. Thompson, Herbert, Messrs. Thompson Brothers, 111 Carver Street, Sheffield.

1896. Thompson, Thomas, General Manager, Australasian Gold Trust, Lindsay Street, Coolgardie, Western Australia: (or care of Alfred Thompson, 20 Bucklersbury, London, E.C.)

1894. Thomson, Henry, Engineer, Cawnpore Woollen Mills, Cawnpore, India.

1893. Thomson, James Watson, Robert Gordon's College, Aberdeen.

1894. Thorpe, Walter Charles, Messrs. Goddard, Massey and Warner, Traffic Street, Nottingham.

1895. Threlfall, George, 50 Fenchurch Street, London, E.C. [*Gasify, London.*]

1893. Tomes, William Jameson, District Locomotive Superintendent, East Indian Railway; care of Joshua Tomes, 5 The Grove, Clacton-on-Sea.

1893. Tomlinson, William Augustus, P.O. Box 1978, Johannesburg, Transvaal, South Africa: (or care of John Tomlinson, Birthorpe Manor, Folkingham.)

1896. Trafford, Alfred, Albion Lamp Works (Rippingille's), Birmingham.

1897. Turner, George Robert, Works Manager, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne.

1893. Turner, Henry Arthur, care of Arthur Koppel, 96 Leadenhall Street, London, E.C.

1896. Turner, James William, Messrs. George Smith and Co., 13 Commercial Road, Pimlico, London, S.W.

1896. Umney, Herbert Williams, 55 Parsonage Road, Withington, Manchester.

1896. Vallint, Frank William, Superintendent, Mullicks Ghat Pumping Station, Calcutta Water Works, Calcutta, India.

1896. Vernon, William Harry, Messrs. E. Green and Son, Wakefield.

1893. Walker, Charles Christopher, Messrs. Walker, Eaton and Co., Wicker Iron Works, Sheffield. [*Founder, Sheffield.* 376.]

1897. Ward, John Cecil, 52 Queen Victoria Street, London, E.C.

1895. Wasdell, Abel, Superintendent, Water Works, Allahabad, India.

1894. Wasdell, Thomas, City Water Works, Edgbaston, Birmingham.

1893. Watson, George, 39 Victoria Street, Westminster, S.W. [*Meterage, London.*]

1897. Waynforth, Harry Morton, King's College, Strand, London, W.C.

1893. Wells, Sidney Herbert, Principal, Battersea Polytechnic Institute, Battersea, London, S.W.

1897. Welsh, John, P.O. Box 1421, Johannesburg, Transvaal, South Africa.

1897. Whale, Ralph Abrahams, Hampton Road, Pitsmoor, Sheffield.

1895. Wild, Adamson George, care of W. S. Laycock, Victoria Street Works, Sheffield.

1893. Wilkins, George Cornelius, Messrs. Walker Brothers, Pagefield Iron Works, Wigan.

1892. Williams, Arthur Edward, Cold Store, Daniel Adamson Road, Mode Wheel, Manchester.

1895. Williams, Henry Watson. Essex Street, Fremantle, Western Australia.

1889. Willis, Edward Turnley, Hockley Hall and Whateley Colliery, Tamworth.

1896. Winston, Harold Holmes, Messrs. Waterlow and Sons, Finsbury, London, E.C.

1896. Wiseman, Alfred, Messrs. Robey and Co., Globe Iron Works, Lincoln; and 45 Princess Road, Edgbaston, Birmingham.

1897. Worsley, Philip John, Jun., Messrs. Nettlefolds, Smethwick, Birmingham.

1895. Wort, Walter Edward, Liquid Fuel Engineering Co., Columbine Ship Yard, East Cowes, Isle of Wight.

1889. Wright, Howard Theophilus, Great George Street Chambers, Westminster, S.W. [*Heaterite, London.* 3248.]

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Tinsley, Sheffield.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland; and The Glen, Newry, Ireland.
1889. Barr, John, The Glenfield Engineering Works, Kilmarnock.
1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield; and 38 Wellington Street, Higher Broughton Manchester.
1890. Birch, John Grant, 10 and 11 Queen Street Place, London, E.C.
1892. Bowman, Frederic Hungerford, D.Sc., F.R.S.E., Mayfield, Knutsford.
1888. Brown, Harold, Messrs. Linklater, Hackwood, Addison and Brown, 2 Bond Court, Walbrook, London, E.C.
1890. Burt, John Mowlem, Messrs. John Mowlem and Co., 19 Grosvenor Road Pimlico, London, S.W.

1889. Castle, Frederick George, East London Technical College, People's Palace, Mile End Road, London, E.
1889. Chamberlain, John George, Messrs. Joseph Wright and Co., Neptune Forge, Tipton.
1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1890. Chubb, Richard, Messrs. Gillison and Chadwick, 10 Tower Buildings, Liverpool.
1893. Clarke, Edward Fuhrmann, Curzon Chambers, Paradise Street Birmingham; and 59 Stanmore Road, Edgbaston, Birmingham.
1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]
1895. Cole, James Conrad, 33 Cecile Park, Crouch End, London, N.
1892. Cooper, Thomas Lancelot Reed, 27 Bothwell Street, Glasgow.
1894. Cowles, Lieut.-Commander William S., U.S.N., care of The Navy Department, Washington, D.C., United States.
1892. Cryer, Arthur, University College, Cardiff.

1892. Davis, George Brown, Palace Wharf, Stangate, London, S.E.; and Overton Lodge, Overton Road, Brixton, London, S.W.

1896. Devine, William Henry, Secretary, Mitsu Bishi Engine Works and Dockyard, Nagasaki, Japan.
1895. Docker, Frank Dudley, Messrs. Docker Brothers, Birmingham Varnish Works, Icknield Port Road Birmingham. [*Japan, Birmingham* 3522.]

1897. Echevarri, Juan Thomas Wood, British Aluminium Co., 9 Victoria Street Westminster, S.W.

1892. Fauvel, Charles James, Fauvel Gold Recovery Co., Broad Street House London, E.C.
1891. Foster, George, Hecla Foundry Steel Works, Sheffield; and Lyme Villa, Rotherham.

1889. Golby, Frederick William, 36 Chancery Lane, London, W.C.
1889. Gregory, George Francis, Boarzell, Hawkhurst.

1896. Harvey, Julius, 11 Queen Victoria Street, London, E.C. [*Crosshead London.*]
1887. Hind, Enoch, Edgar Rise, Nottingham.
1896. Hutton, William, P.O. Box 2399, Johannesburg, Transvaal, South Africa.

1891. Jackman, Joseph, Persberg Steel Works, Pothouse Road, Attercliffe, Sheffield. [*Persberg, Sheffield.* 94.]
1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]
1897. James, Albert Alfred, St. George's Works, Paradise Street, West Bromwich. [*James, Wireworks, West Bromwich.* 5014.].

1896. Kennan, Williams Thomas, Messrs. Kennan and Sons, Fishamble Street, Dublin. [*Kennans, Dublin.*]
1897. Kenway, William Edward, Messrs. Caswell and Bowden, 1–3 Burlington Chambers, New Street, Birmingham.
1896. King, Benjamin Thomas, 163 Queen Victoria Street, London, E.C. [*Apis, London.* 1682.]
1896. Kitto, William Henry, Morvah, Hartington Road, Grove Park, London, W.

1896. Lemkes, Carl Rudolf Lewin, Messrs. Schäffer and Budenberg, 194 and 196 Hope Street, Glasgow. [*Injector, Glasgow.* 3119.]
1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.* 131.]

1895. MacBrayne, Laurence, 119 Hope Street, Glasgow.

1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.

1896. Marshall, Lewis, Messrs. Lumby, Son, and Wood, West Grove Works, Halifax. [*Lumby, Halifax.* 5 A.]

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]

1890. McGillivray, William, Messrs. Austin McGillivray and Co., Falcon Works, Sheffield. [*Falcon, Sheffield.*]

1889. McKinnel, William, 234A Nithsdale Road, Pollokshields, Glasgow.

1890. Meggitt, Samuel Newton, Messrs. Ibbotson Brothers and Co., Globe Steel Works, Sheffield.

1896. Naylor, Sam, Messrs. Lumby, Son, and Wood, West Grove Works, Halifax. [*Lumby, Halifax.* 5 A.]

1887. Neville, Edward Hermann, 35 Calle de Alcala, Madrid, Spain.

1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]

1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.

1888. Peake, Robert Cecil, Cumberland House, Redbourn, near St. Albans.

1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield; and 49 Victoria Street, Westminster, S.W.

1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield; and Fernbank, Roehampton Park, London, S.W.

1894. Peters, Lindsley Byron, Messrs. G. D. Peters and Co., Moorgate Works, Moorfields, London, E.C. [*Peters, London.*]

1884. Phillips, Richard Morgan (*Life Associate*), 21 to 24 State Street, New York, United States.

1891. Plant, George, Moseley Road School, Birmingham.

1897. Prior, James D., Eagle Range and Foundry Co., Catherine Street, Aston, Birmingham. [*Ranges, Birmingham.* 2558.]

1891. Rankin, Thomas Thomson, Principal, Coatbridge Technical School and West of Scotland Mining College, Coatbridge.

1892. Reed, Ernest Charles, Riverside Mills, Dartford.

1891. Rowcliffe, William Charles, 1 Bedford Row, London, W.C.

1888. Rowell, John Henry, New Brewery, High Street, Gateshead.

1896. Sangster, William Skene, Superintendent, Lima Water Works, Lima, Peru.

1890. Schofield, John William, Messrs. Gregory and Bramall, Soho Steel and File Works, Sheffield.

1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]

1893. Simpson, Edward Percy, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1897. Smith, William Henry, Manager, Platinotype Engineering Co., Platinotype Works, Penge, London, S.E.

1891. Spencer, Francis Henry, P.O. Box 1338, Johannesburg, Transvaal, South Africa.

1897. Starley, William, Queen Victoria Road, Coventry. [*Salvo, Coventry.* 72.]

1892. Stead, John Edward, 11 Queen's Terrace, Middlesbrough. [*Stead, Middlesbrough.*]

1890. Taylor, John, 99 and 101 Fonthill Road, Finsbury Park, London, N.; and Stockport.

1896. Taylor, Joseph Henry, 9 and 11 Fenchurch Avenue, London, E.C. [*Tyne, London.* 4108.]

1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1893. Wadham, Arthur, 171 Queen Victoria Street, London, E.C. [*Wadham, London.*]

1897. Wallach, Lewis Charles, 57 Gracechurch Street, London, E.C. [*Hammerman, London.*]

1892. Whitehead, Richard David, Municipal Technical College, Green Hill, Derby.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

1891. Wiseman, Edmund, Cheapside and John Street, Luton. [*Wiseman, Luton.*]

1897. Wood, William Alfred, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester.

GRADUATES.

1885. Addis, Frederick Henry, District Locomotive Superintendent, Rajputana-Malwa Railway, Sirsa, Punjaub, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1895. Alcock, Alfred Edwin, Yorkshire Engine Works, Sheffield.

1893. Alderson, Charles Albert Heselton, Norland House, Ramleh, Alexandria, Egypt.

1897. Allan, Frederick William, 1 Cecil Street, Paisley Road West, Glasgow.

1897. Allan, George, Jun., Corngreaves Hall, near Birmingham.

1894. Ambrose, Sewell Powis, 163 Trafford Road, Salford, Manchester.

1882. Anderson, William, 19 Normandy Terrace, Gateshead.

1897. Atherton, Percy William, Messrs. Maudslay, Sons and Field, Lambeth, London, S.E.

1890. Aubin, Percy Adrian, 29 St. James' Street, St. Helier's, Jersey.

1888. Bailey, Wilfred Daniel, Messrs. Bailey Walker and Co., 454–456 Calle Cuyo, Buenos Aires, Argentine Republic.

1894. Barber, Edward Whitley, 11 Portland Grove, Fallowfield, Manchester.

1896. Barbosa, Agenor, Juiz de Fora, Minas Geraes, Brazil.

1889. Barrow, Arthur Robert Maclean, care of Messrs. William Watson and Co., 28 Apollo Street, Bombay, India: (or care of Mrs. Barrow, Holly Grove, Fittleworth, Pulborough.)

1897. Bartley, Bryan Cole, Naval Construction and Armaments Works, Barrow-in-Furness.

1897. Baxandall, Richard Fitzgerald, Gregneish, Ben Rhydding, Leeds.

1884. Bell, Robert Arthur, Assistant Locomotive and Carriage Superintendent, South Indian Railway, Negapatam, Madras, India: (or care of Mrs R. C. Bell, 30 Egerton Crescent, London, S.W.)

1896. Bigger, Courtenay, Falmore Hall, Dundalk, Ireland.

1895. Blair, George, 16 Albert Road (East), Crosshill, Glasgow.

1897. Bowden, John Horace, Great Central Railway, Gorton, Manchester.

1888. Bradley, Arthur Ashworth, Princess Estate and Gold Mining Co., Roodepoort, near Johannesburg, Transvaal, South Africa: (or care of Rev. Gilbert Bradley, St. Edmund's Vicarage, Dudley, Worcestershire.)

1887. Bremner, Bruce Laing, Assistant Locomotive Superintendent, Uganda Railway, Mombasa: (or care of Mrs. Bremner, Streatham, Canaan Lane, Edinburgh.)

1894. Britten, Thomas, Electric Construction Company, Wolverhampton.

1890. Brousson, Robert Percy, Electric Traction Co., 16 Great George Street, Westminster, S.W.

1880. Buckle, William Harry Ray, 11 Billiter Buildings, 49 Leadenhall Street, London, E.C.

1897. Bullock, Richard Cecil, Messrs. Stothert and Pitt, Newark Foundry, Bath.

1891. Butcher, Walter Edward, Messrs. S. Z. de Ferranti, Hollinwood, Manchester.

1891. Caswell, Charles Henry, 75 Mount Pleasant, Barrow-in-Furness.

1894. Cater, John McIlvaine, Southdown, The Downs, Wimbledon.

1890. Chatwood, Arthur Brunel, Chatwood's Safe and Lock Co., 76 Newgate Street, London, E.C. [*Chatwood, London.* 6835.]

1895. Clarke, Leigh Theophilus, Atlingworth, Beckenham.

1892. Cleverly, William Bartholomew, 33 Ivydale Road, Nunhead, London, S.E.

1892. Collingridge, Harvey, Messrs. S. Pearson and Son, Blackwall Tunnel Works, East Greenwich, London, S.E.; and Ingleborough, The Ridgway, Enfield.

1889. Cook, George Norcliffe, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1896. Crow, Lewis, 9 East Lane, Ferguslie, Paisley.

1891. Cutler, Samuel, Jun., Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.

1894. Darwood, John William, Ahlone, Rangoon, Burma.

1896. Davson, Stephen Frederick, 203 Maida Vale, London, W.

1896. Dawe, John Nanscawen, Bank House, Wadebridge, Cornwall.

1884. Dixon, John, 24 Formby Street, Formby, Liverpool.

1897. Donkin, Albert Henry, Jokai (Assam) Tea Co., Lahwal, Dibrugarh, Upper Assam, India.

1893. Douglas, William Saunders, Consett Iron Works, Consett, R.S.O., County Durham; and 60 Durham Road, Blackhill, R.S.O., County Durham.

1895. Dresser, Charles, 5 Marius Road, Balham, London, S.W.

1896. Dryden, William, Jun., Grimshaw Street Foundry, Preston.

1891. Duncan, Martin Gordon, Lexden, 63 Elmfield Road, Upper Tooting, London, S.W.

1896. Edwards, James George Benjamin, Leeds Southern Higher Grade School, Bewerley Street, Leeds.

1897. Emery, James Inman, care of Edwin A. Mansfield, Moorgate Station Chambers, London, E.C.

1897. Engelbach, Charles Richard Fox, Sir W. G. Armstrong, Whitworth and Co., Elswick Works, Newcastle-on-Tyne.

1897. Etlinger, George Ernest, 17 Gower Street, London, W.C.

1897. Evetts, William, Jun., Lancashire and Yorkshire Railway, Horwich, near Bolton.

1895. Ferguson, Victor Bruce, Altidore Villa, Pittville, Cheltenham.

1896. Fiegehen, Edward George, Bedford Engineering Works, Bedford.

1897. Foster, Sydney, Engineer's Office, Lancashire and Yorkshire Railway Fleetwood, R.S.O., Lancashire.

1897. Fox, Beaufoy Howard, British Dooars Co., Panabustie P.O., Buxa Dooars, Bhootan, India.

1893. Fox, Frederick Joseph, 102 Fenchurch Street, London, E.C.

1895. Fryer, Tom Jefferson, Totley Brook, near Sheffield.

1895. Gale, Robert Henry, 38 Scarsdale Villas, Kensington, London, W.

1895. Gill, Charles Edgar, 9 Balmoral Place, Halifax.

1896. Goddard, William Herbert, Pinkthorne, Canning Road, Addiscombe, Croydon.

1897. Godson, Edward Harold, Cheadle House, Cheadle, Cheshire.

1896. Gordon, Leslie, Bentley Priory, Stanmore.

1897. Goulding, Benjamin Joseph John, Messrs. Joseph Foster and Sons, 20 Whitefriars Street, London, E.C.

1897. Guthrie, William James, Templehill, Troon.

1895. Hall, William Brasier, H.M.S. "Impérieuse," Pacific Station: (or Inglewood, Christ Church Road, Cheltenham.)

1889. Hayward, Robert Francis, Union Light and Power Co, Salt Lake City, Utah, United States.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1893. Heinrich, Herbert Rodolph, Fern Cottage, Chantry Road, Chertsey.

1896. Hodgson, George Henry, care of I. W. Boultbee, Strathfield, Sydney, New South Wales.

1891. Hodgson, William James, Messrs. Hodgson and Hodgson, Central Chemical Works, Nottingham.

1887. Hogg, William, Craigmore, Blackrock, Dublin.

1897. Hollingsworth, Allen Alexander, Messrs. Henry Bessemer and Co., Carlisle Street East, Sheffield.

1889. Hosgood, Thomas Watkin, Eaton Grove, Swansea.

1889. Howard, Geoffrey, Britannia Iron Works, Bedford.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.
1891. Hughes, Edward Sinclair Bremner, 16 Court Road, West Norwood, London, S.E. [*Sirhind, London.*]
1896. Humphrey, Frederick George, 166 High Street, Sevenoaks.

1896. Johnson, Henry Howard, Geelong Gold Mining Co., Gwanda, Matabeleland.
1894. Johnson, Walter Wroe, Castleton Foundry and Engineering Works, Armley Road, Leeds.
1890. Jones, Arthur Dansey, Carriage and Wagon Department, Lancashire and Yorkshire Railway, Victoria, Manchester.
1891. Jordan, Frederic William, 42 Wells Street, Mortimer Street, Cavendish Square, London, W.

1895. Keen, Harry A., Patent Nut and Bolt Co., London Works, near Birmingham.
1896. Kitsell, Archibald Edward, 24 St. Stephen's Avenue, Shepherd's Bush, London, W.
1896. Knight, Stephenson Yates, Viaduct Foundry and Engineering Works, Crumlin, R.S.O., Monmouthshire.

1883. Lander, Philip Vincent, Woodside House, Wimbledon: (or care of W. W. Lander, Imperial Ottoman Bank, 26 Throgmorton Street, London, E.C.)
1894. Larmuth, William Oliver, Messrs. Thomas Larmuth and Co., Todleben Iron Works, Unwin Street, Cross Lane, Salford, Manchester; and 103 York Terrace, Eccles Old Road, Pendleton, Manchester.
1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and Glan-y-Dwr, Llandaff, near Cardiff.
1894. Lloyd, Thomas Zachary, Messrs. Nettlefolds, Smethwick, Birmingham and Areley Hall, Stourport.
1897. Locket, Athol, Woodlands, Muswell Hill Road, Highgate, London, N.

1883. Mackenzie, Thomas Brown, Messrs. David Colville and Sons, Dalzell Steel and Iron Works, Motherwell; and 342 Duke Street, Glasgow.
1893. Mackesy, Walter, 20 Suffolk Street, Jarrow.
1897. Mansfield, Frank, Messrs. P. Orr and Sons, Mount Road, Madras, India.
1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.
1892. Marks, Alfred Pally, 98 Gillott Road, Birmingham.
1895. Marriner, John, 9 Gloucester Place, Greenwich, London, S.E.

1889. Marshall, Frank Theodore, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1896. Marshall, John Frederick, King's College, Cambridge.

1888. Marten, Hubert Bindon, Contractor's Office, Metropolitan Railway Widening, 50 Iverson Road, London, N.W.; and Pedmore Stourbridge.

1886. Mattos, Alvaro Gomes de, 98 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1897. Maw, Henry, 17 Victoria Street, Westminster, S.W.

1897. McGregor, John Leith, Coatbank Engine Works, Coatbridge.

1892. Miles, Frederick Hudson, Hampden House, Phœnix Street, St. Pancras, London, N.W.

1891. Mills, Matthew William, Moss Foundry, Heywood, near Manchester.

1891. Mogg, Henry Hodges, Newbridge Hill, near Bath.

1897. Montgomery, Charles Hubert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1894. Moon, Edgar Rupert, Locomotive Superintendent, Midland Railway of Western Australia, St. George's Terrace, Perth, Western Australia: (or care of J. E. Moon, Cloudesleigh, Brixton, near Plymouth.)

1896. Morton, John Henry, care of Miss Grist, 52 Wellington Road, St. John's Wood, London, N.W.

1897. Muggeridge, Harold Chisman, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1892. Murray, David James, Thorn House, Johnstone, near Glasgow.

1897. Nixon, Charles Basil, 38 Bidston Road, Birkenhead.

1883. O'Connor, John Frederick, Messrs. O'Connor and Rutherford, 31 and 33 Broadway, New York, United States.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1897. Oswald, George Herbert, 19 High Road, Streatham, London, S.W.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.

1895. Palmer, Henry Boswell, Jun., Heathfield Lodge, Gunnersbury Lane, Acton, London, W.

1887. Paterson, John Edward, Chief Mechanical Engineer's Office, New South Wales Government Railways, Wilson Street, Eveleigh, Sydney, New South Wales.

1894. Petter, Percival Waddams, The Foundry, Yeovil.

1890. Philipson, John, Jun., Messrs. Atkinson and Philipson, 27 Pilgrim Street Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1884. Philipson, William, Messrs. Atkinson and Philipson. 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1897. Pillatt, Andrew Ernest, Messrs. A. Pillatt and Co., Queen's Road Works, Nottingham.

1896. Pinel, Paul Gustave Marie, Messrs. Lethuillier and Pinel, 24 bis Rue Méridienne, Rouen, France.

1890. Powell, Frederick, York House, Malvern Link, Malvern.

1892. Power, Arthur Cyril, 17 Fordwych Road, Brondesbury, London, N.W.

1893. Price, William Frederick, Wyresdale, Wilbraham Road, Chorlton-cum-Hardy, Manchester.

1897. Pullar, Frederick Pattison, Messrs. Robert Pullar and Sons, Keirfield, Bridge of Allan, N.B.

1897. Rainforth, William Frederick, Messrs. Rainforth and Sons, Britannia Iron Works, Lincoln.

1892. Ransom, Herbert Byrom, Messrs. Manlove Alliott and Co., 57 Gracechurch Street, London, E.C.

1895. Read, George Henry, 7 Palmerston Road, Bowes Park, London, N.

1894. Readhead, Robert, Jun., Messrs. John Readhead and Sons, West Docks, South Shields.

1884. Reynolds, Thomas Blair, 28 Victoria Street, Westminster, S.W.

1895. Riches, Carlton Tom Hurry, 8 Park Grove, Cardiff.

1892. Ridley, James Cartmell, Jun., 3 Summerhill Grove, Newcastle-on-Tyne.

1895. Roberts, Basil Owen, Cooper Steam Digger Co., King's Lynn.

1897. Robinson, Herbert, Long Wall Side, Low Moor, near Bradford.

1897. Rootham, Howard Melville, 26 Granville Place, Portman Square, London, W.

1896. Rosevere, Gerald Rhodes, Great Western Railway, Stafford Road Works, Wolverhampton; and care of W. S. Rosevere, The Manor House, Tavistock, Devon.

1896. Rothschild, Lester Vivian, 10 Gloucester Terrace, Hyde Park, London, W.

1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.

1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.

1894. Russell, William Colin, Gwalia Tin-Plate Works, Briton Ferry; and Hafod, Swansea.

1890. Saxelby, Herbert Raffaelle, 7 and 8 Ironmonger Lane, Cheapside London, E.C.

1892. Scarfe, George Norman, care of George Scarfe, Gawler Place, Adelaide, South Australia.

1881. Scott, Ernest, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]

1892. Shepherd, James Horace, Great Western Railway, Swindon.

1887. Simkins, Charles Wickens, Jun., Amguri Tea Estate, Amguri Post Office, Sibsagar, Assam, India: (or care of Charles W. Simkins, The Lodge, Lowdham, near Nottingham.)

1894. Simpson, Lightly Stapleton, Trinity College, Cambridge; and 16 Kent Terrace, Regent's Park, London, N.W.

1896. Simpson, Norman De Lisle, Trafalgar Works, Bridgetown, Barbados, West Indies.

1897. Slingsby, Walter, Norwood House, Keighley.

1895. Smith, Frederick Hardcastle, Steam Crane Works, Old Foundry, Rodley, near Leeds.

1892. Stokes, Frank Torrens, P.O. Box 1355, Johannesburg, Transvaal, South Africa.

1883. Swale, Gerald, Hotel St. Petersbourg, Rue Caumartin, Paris.

1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1884. Taylor, Joseph, Norville, Eaton Road, Heaton Chapel, near Stockport.

1884. Taylor, Maurice, 39 Rue de Lisbonne, Paris.

1896. Thom, Frank, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1894. Thorpe, Wilfred Bertram, 20 Larkhall Rise, Clapham, London, S.W.

1895. Titren, Gerald Ernest de Keyser, Natal Government Railway Works, Durban, Natal.

1892. Vezey, Albert Edward, 150 Virginia Street, Southport.

1888. Waddington, Samuel Sugden, 35 King William Street, London Bridge, London, E.C.

1897. Wade, Francis Richard, Gothic House, Beeston, Nottingham.

1896. Walker, Charles Bell, Bell-Walker Machine Co., 164 Deansgate, Manchester.

1888. Waring, Henry, Engineer, Dublin Laundry Co., Milltown, near Dublin.

1892. Warton, Richard George Frank, The Dingle, Chepstow.

1895. Waugh, Hylton Norman Drake, Locomotive Department, London Brighton and South Coast Railway, Brighton.

1886. Wesley, Joseph A., Messrs. Woodhouse and Rixson, Chantrey Steel and Crank Works, Sheffield.

1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 44 Trumpington Street, Cambridge.)

1894. Whitelegg, Robert Harben, Locomotive Department, London Tilbury and Southend Railway, Plaistow, London, E.

1889. Wigham, John Cuthbert, Electric Light Station, Shrewsbury.

1895. Wilkin, Ernest Vivian, Northumberland Engine Works, Wallsend-on-Tyne; and 11 Appold Street, Finsbury, London, E.C.

1897. Williams, Hal, 23 King's Road, Kingston-on-Thames.

1896. Williams, Llewellyn Wynn, Railway Appliances Works, Cathcart, Glasgow.

1890. Wilson, Alexander Cowan, Manchester Sheffield and Lincolnshire Railway, The Newarke, Leicester; and Osgathorpe Hills, Sheffield.

1897. Wilson, Robert James, Messrs. John I. Thornycroft and Co., Church Wharf, Chiswick, London, W.

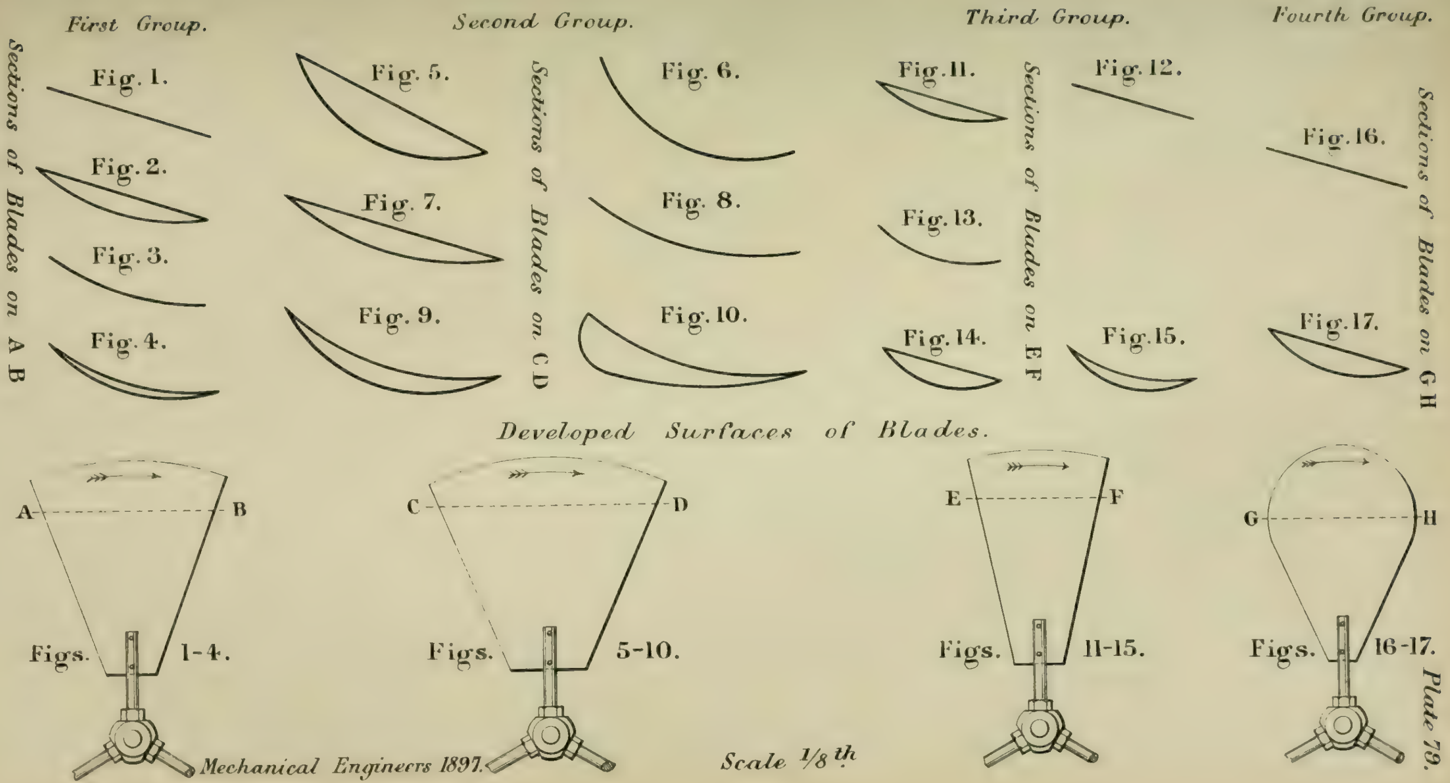
1896. Winlaw, William Willoughby, Sir W. G. Armstrong, Whitworth and Co., Elswick Works, Newcastle-on-Tyne.

1890. Wright, William Carthew, General Post Office, Melbourne, Victoria: (or care of Dr. Gaskoin Wright, 253 Eccles New Road, Salford, Manchester.)

1895. Yeames, James Lamb, care of Pedro Christophersen, 249 Calle Cuyo, Buenos Aires, Argentine Republic: (or care of J. G. Scaramanga, 4, 5 and 6 Great St. Helen's, London, E.C.)

1891. Yerbury, Frederick Augustus, 17 Victoria Street, Westminster, S.W,

PROPELLER VENTILATING FANS.



Mechanical Engineers 1897.

Scale 1/8th.

PROPELLER VENTILATING FANS.

Fan-Testing Apparatus.

Electric Motor and Fan with three blades.

Fig. 18. *Plan.*

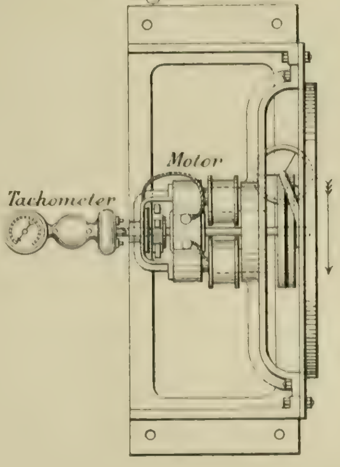
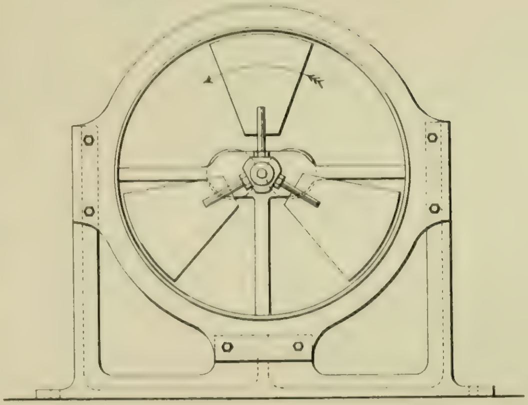
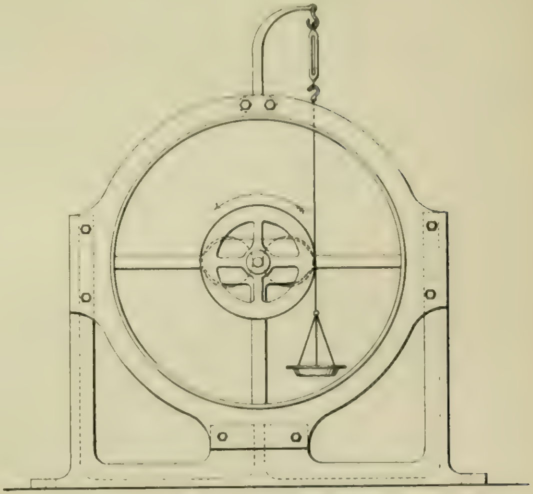


Fig. 19. *End Elevation.*



Brake Dynamometer.

Fig. 20. *End Elevation.*



Scale 1/16th.

Inches 10 5 0 10 20 30 *Inches*

Mechanical Engineers 1897.

Plate 80.

PROPELLER VENTILATING FANS.

Plate 81.

Fan-Testing Apparatus.

Arrangement of Motor
and Delivery Air-Tube.

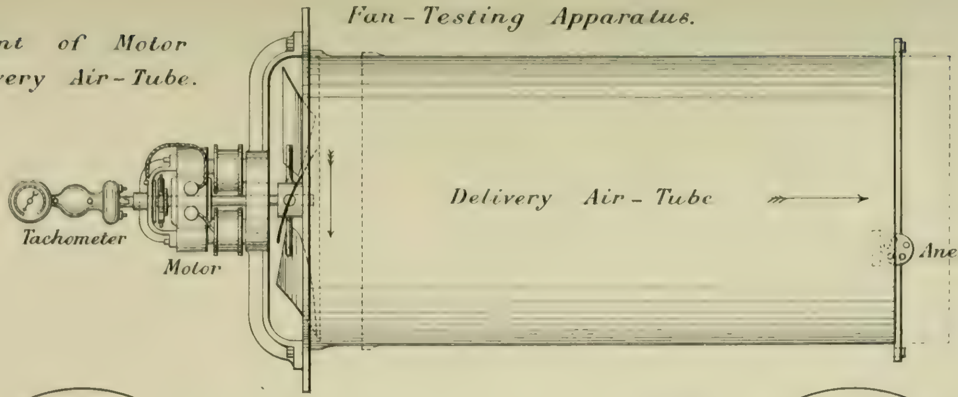
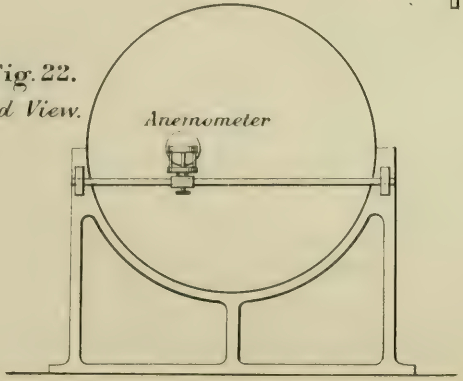


Fig. 21.
Plan.

Fig. 22.
End View.



				Sq. Foot
Area	of	ring	A =	1·275
"	"	"	B =	0·945
"	"	"	C =	0·614
"	"	"	D =	0·307
Total area of tube				3·141

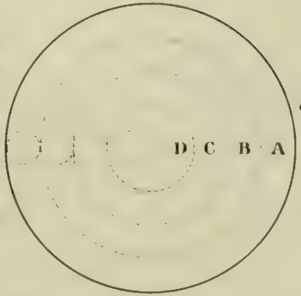


Fig. 23. Radii at which velocities were taken.

Scale $1/16^{th}$.

Mechanical Engineers 1897.

Plate 81.

PROPELLER VENTILATING FANS. *Plate 82.*

Series Electric Motor.

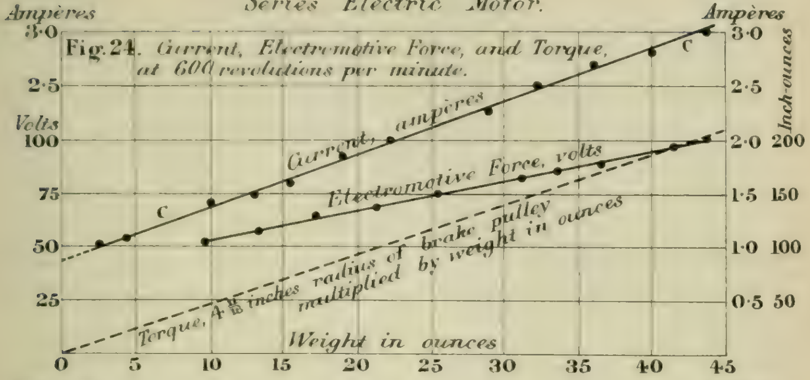


Fig. 24. *Current, Electromotive Force, and Torque, at 600 revolutions per minute.*

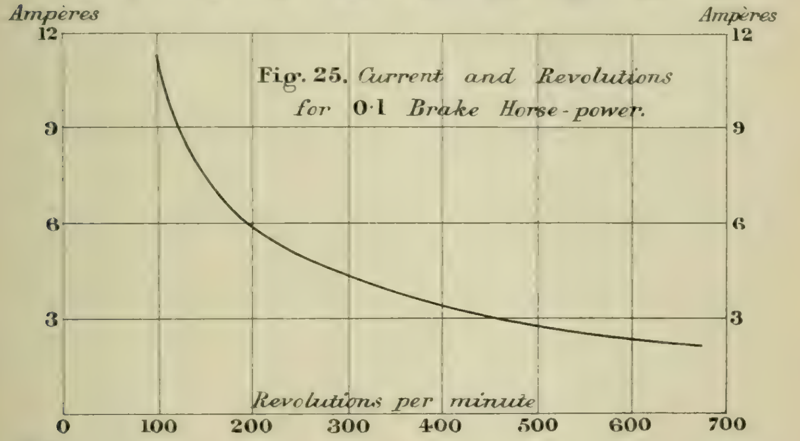


Fig. 25. *Current and Revolutions for* **0·1** *Brake Horse-power.*

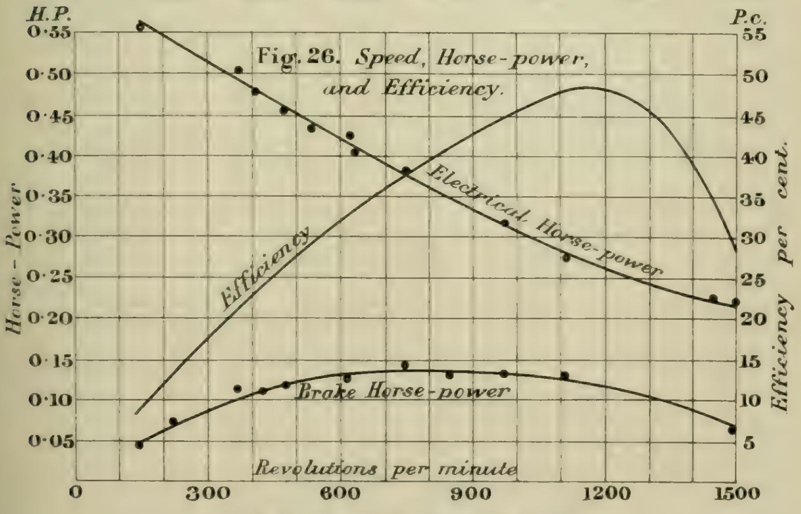


Fig. 26. *Speed, Horse-power, and Efficiency.*

PROPELLER VENTILATING FANS.

Fans 1-2-3-4, angle of blades 17°.

Fan 9, angle of blades 27°.

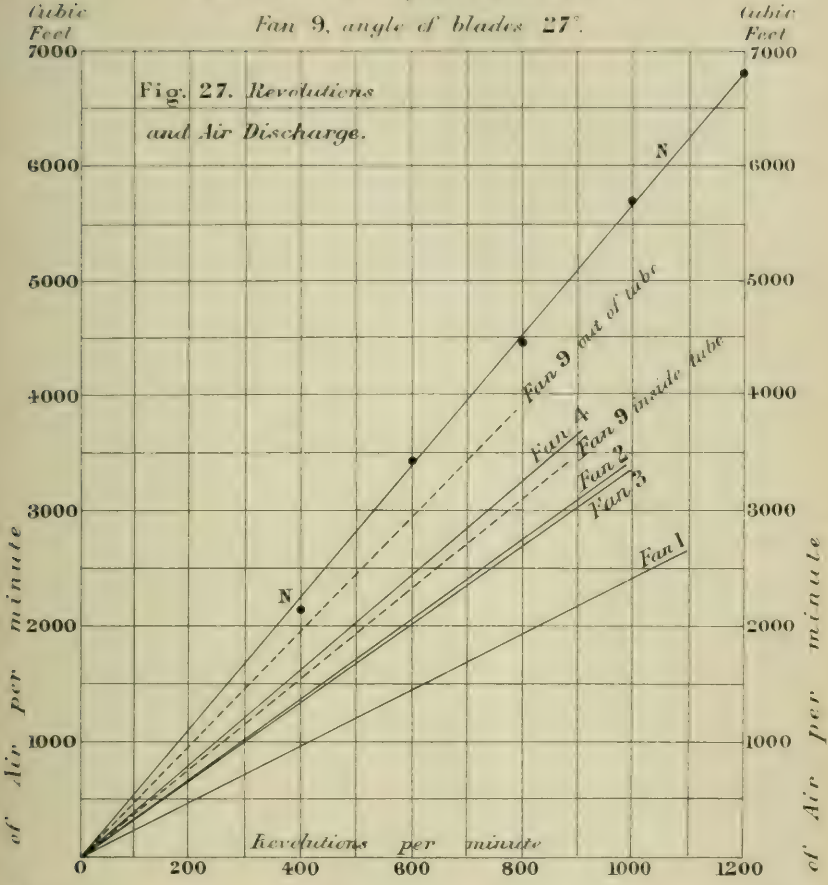


Fig. 27. *Revolutions and Air Discharge.*

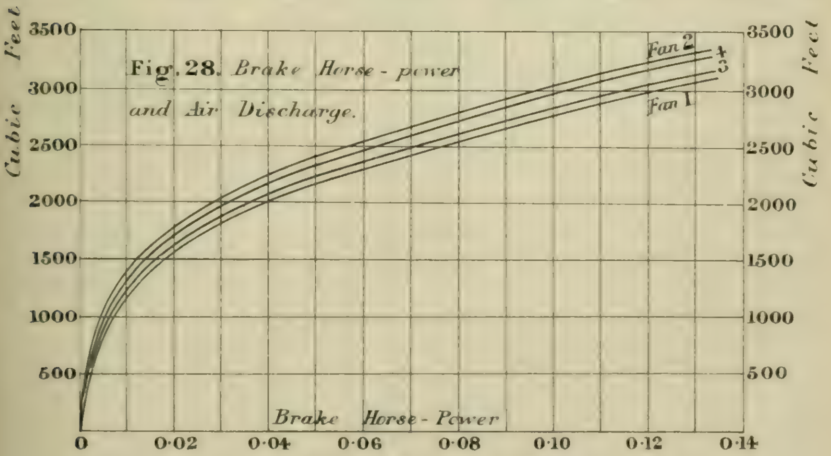
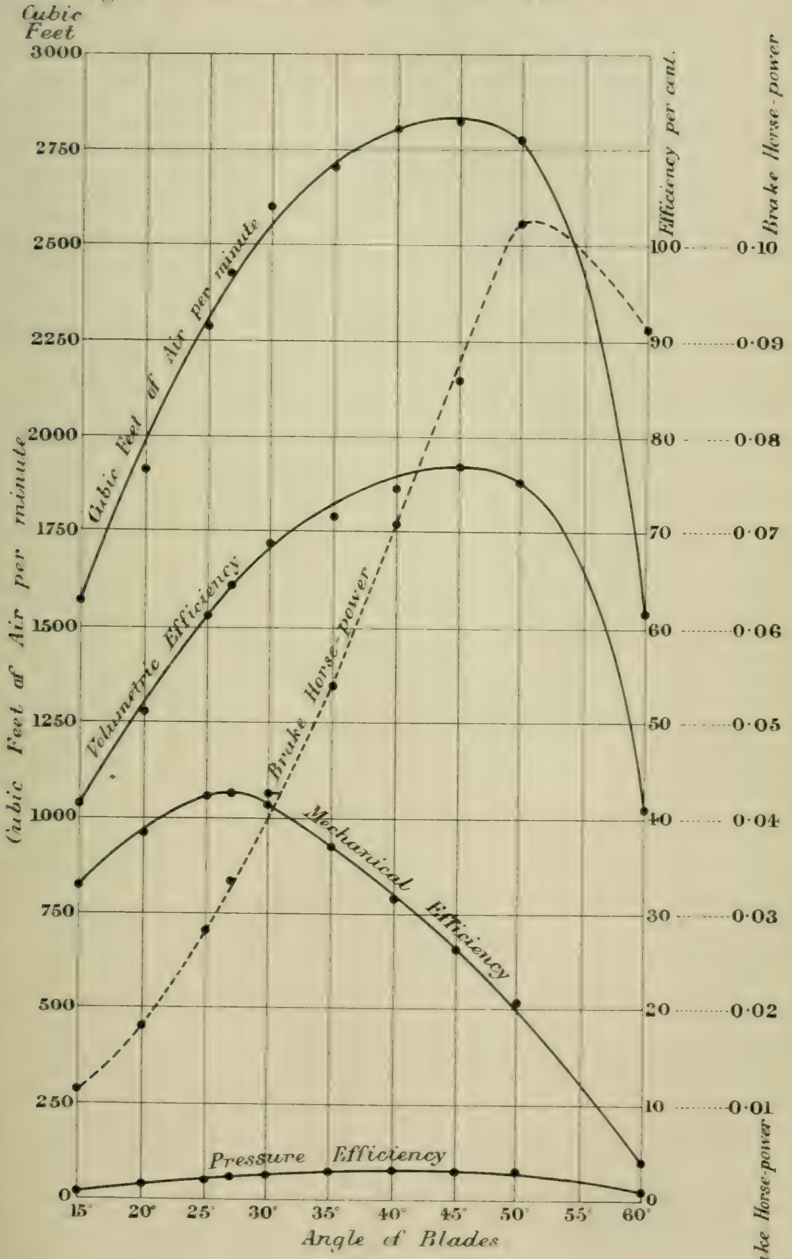


Fig. 28. *Brake Horse-power and Air Discharge.*

Fig. 29. *Characteristic Curves of Fan 17.*



Mechanical Engineers 1897.

PROPELLER VENTILATING FANS. *Plate 85.*

Fans 16 and 17.

Friction of Motor included.

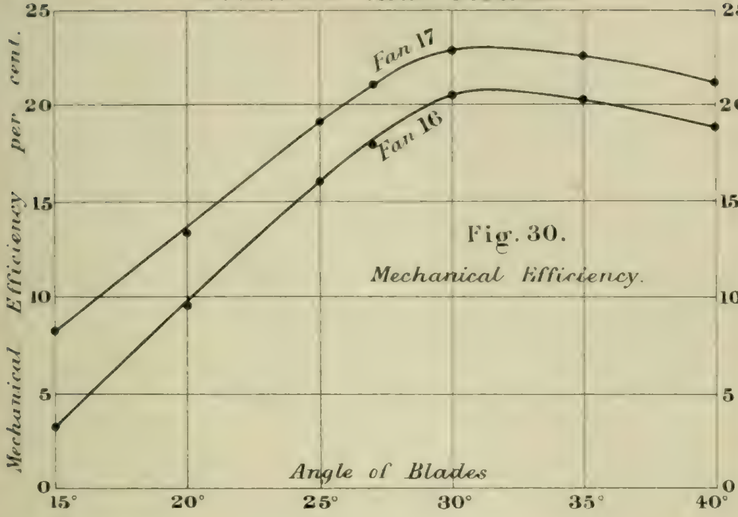


Fig. 30.

Mechanical Efficiency.

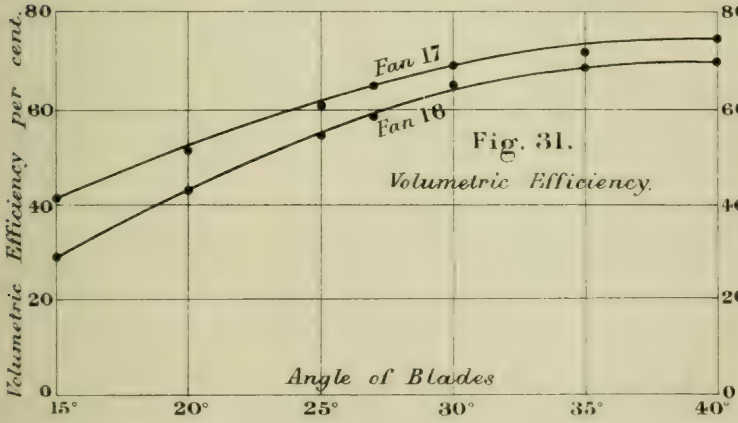


Fig. 31.

Volumetric Efficiency.

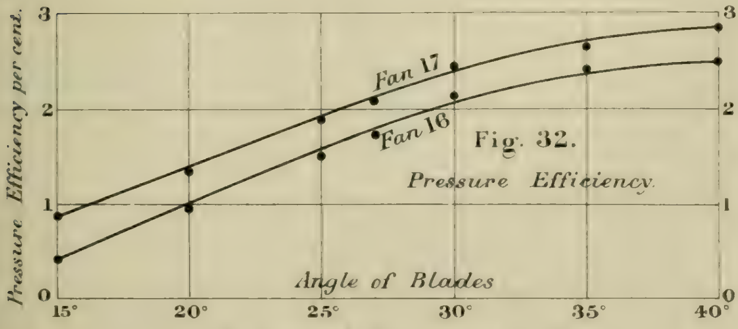


Fig. 32.

Pressure Efficiency.

PROPELLER VENTILATING FANS.

24 - *inch Fan.*

Fig. 33.

Side Elevation.

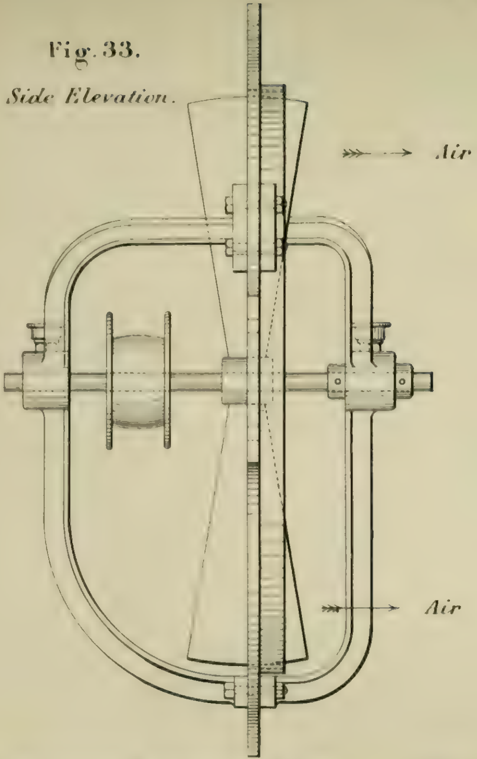
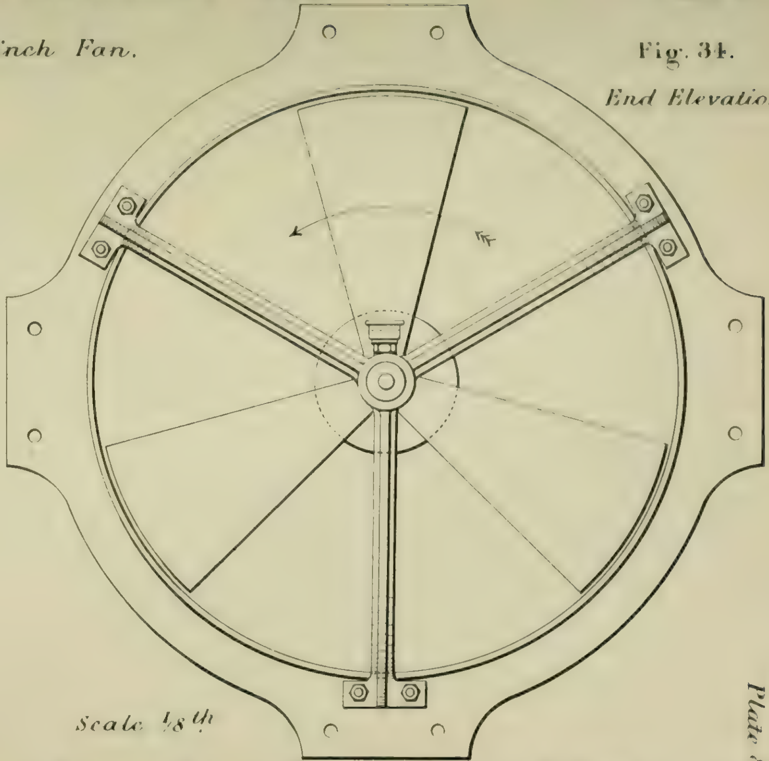


Fig. 34.

End Elevation.

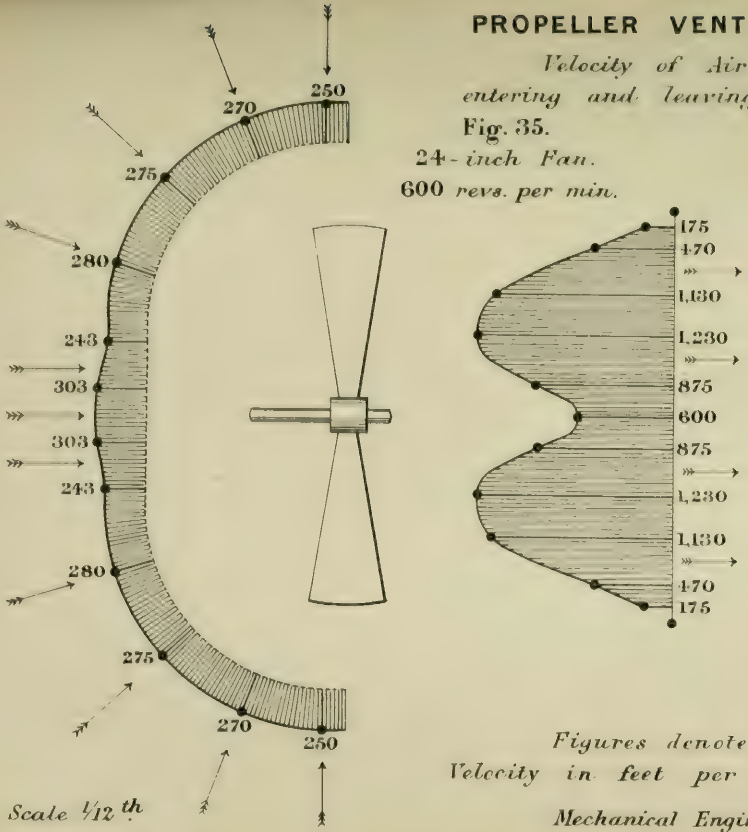


Scale 1/8th.

PROPELLER VENTILATING FANS.

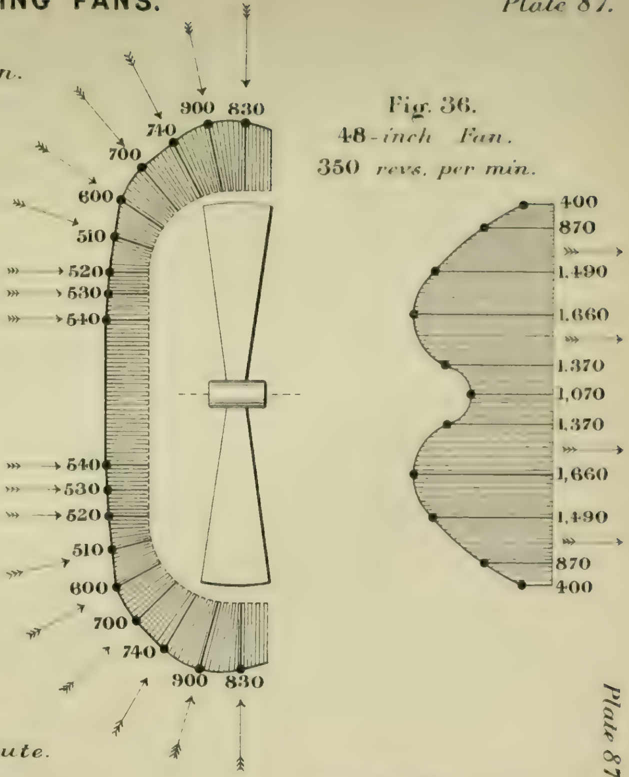
Velocity of Air entering and leaving fan.

Fig. 35.
24-*inch Fan.*
600 *revs. per min.*



Scale 1/12 th.

Fig. 36.
48-*inch Fan.*
350 *revs. per min.*



Scale 1/24 th.

Figures denote
Velocity in feet per minute.

Mechanical Engineers 1897.

PROPELLER VENTILATING FANS.

48 - *inch Fan.*

Fig. 37.
End Elevation.

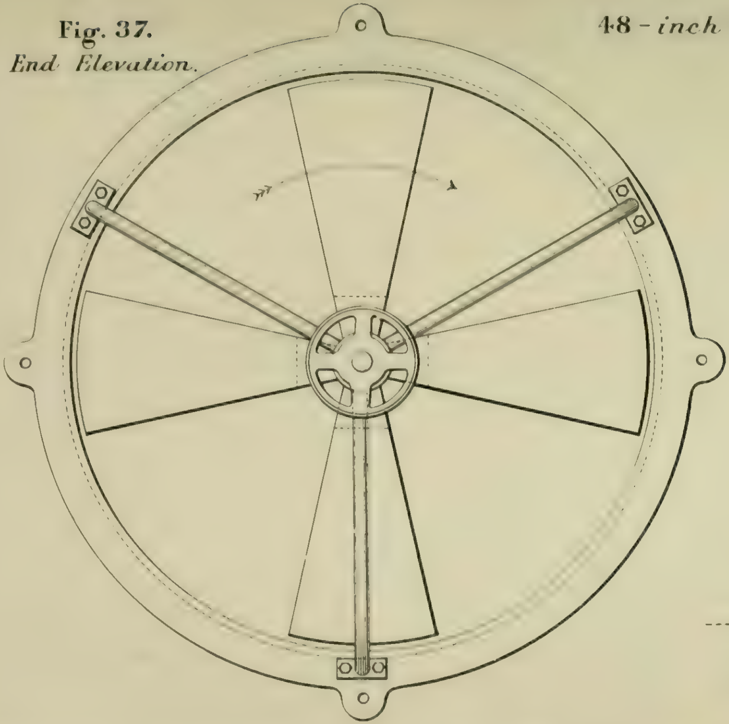


Fig. 38.
Side Elevation.

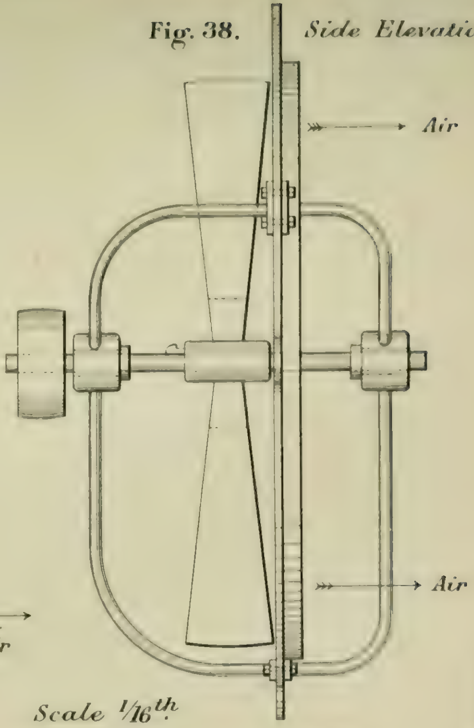
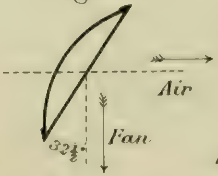


Fig. 39.



Scale 1/16th.

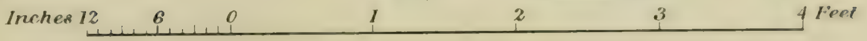


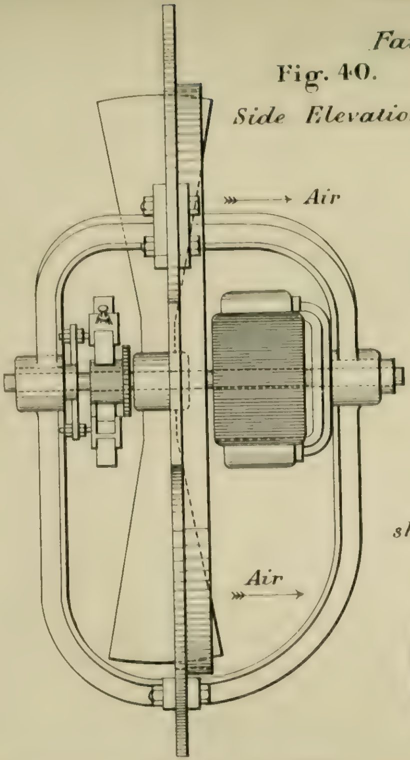
Plate 88.

PROPELLER VENTILATING FANS.

Fan combined with Electric Motor.

Fig. 40.

Side Elevation.



Scale ⅛th.

Fig. 41.

End Elevation.

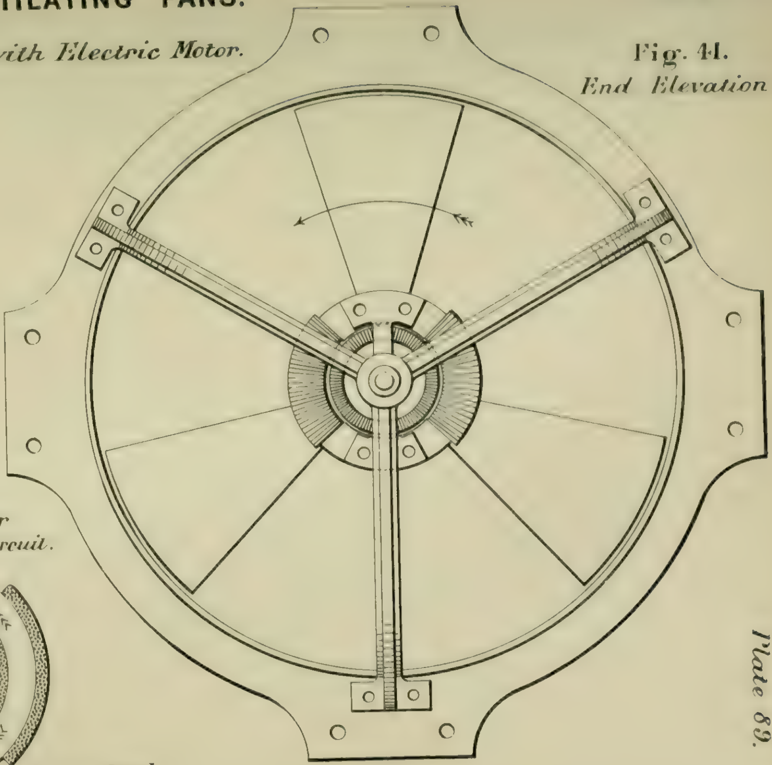
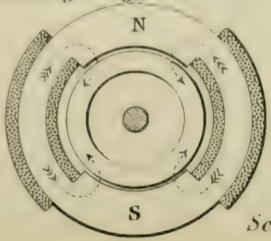


Fig. 42.

Section of Motor showing magnetic circuit.



Scale ⅙th.

PROPELLER VENTILATING FANS.

Contracted Outlet with Disc DD. Propelling.

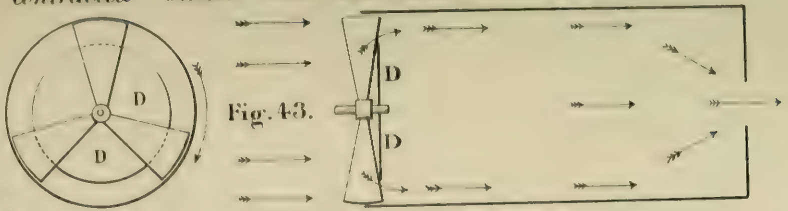


Fig. 43.

Contracted Inlet with Disc DD. Exhausting.

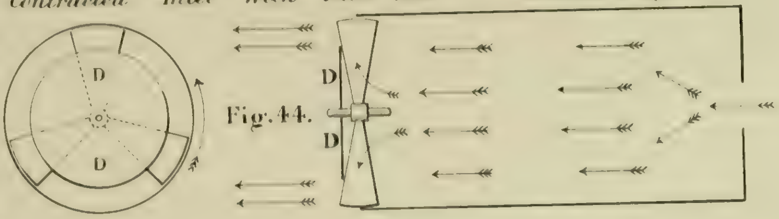


Fig. 44.

Contracted Outlet without Disc. Circulating.

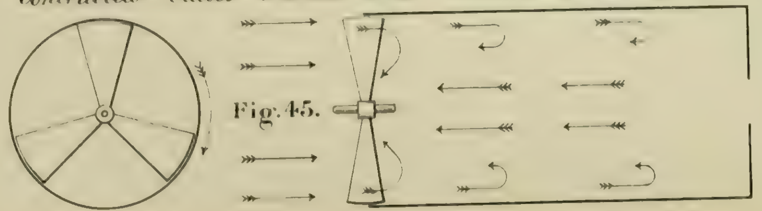


Fig. 45.

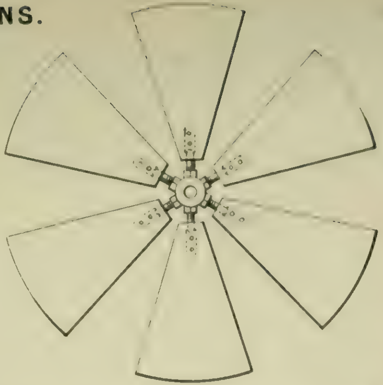


Fig. 46.

Fans with different numbers of Blades.

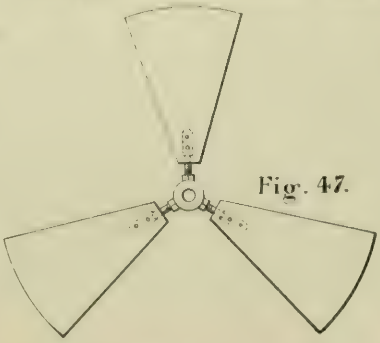


Fig. 47.

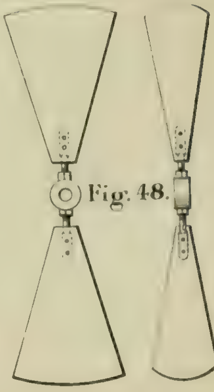


Fig. 48.

Scale 1/12 th.

Plate 90.

PROPELLER VENTILATING FANS.

Helical Blades.

24-inch Fan.

Scale 1/4th.

Fig. 49. Pitch 3 feet.

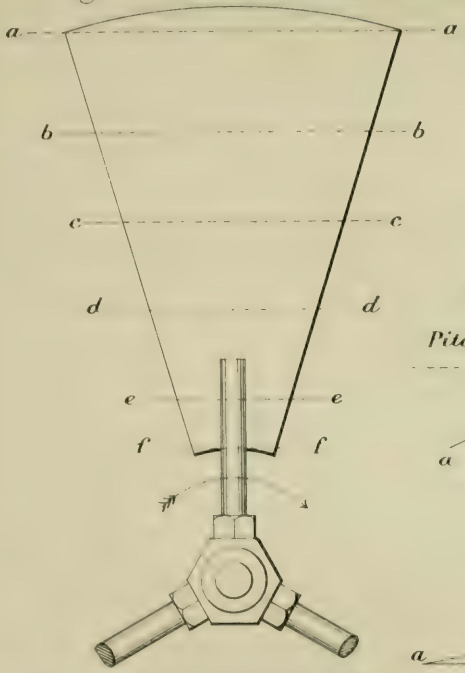
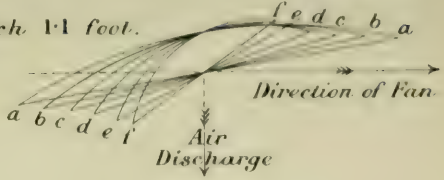


Fig. 52. Cross Sections of Blades.

Pitch 1·1 foot.



Plans showing Blade Angles at different radii.

Fig. 50.

Pitch 3 feet.

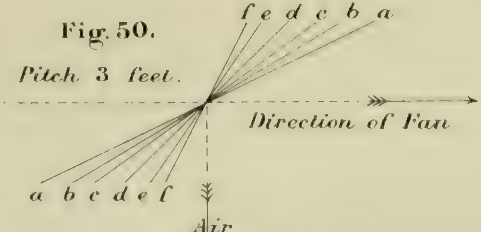


Fig. 51.

Pitch 1·1 foot.

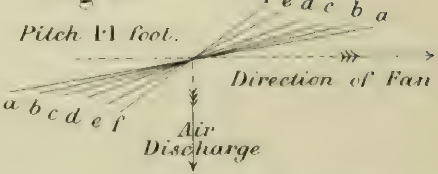
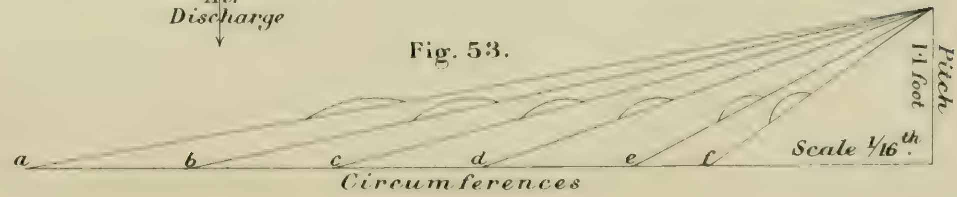


Fig. 53.



Mechanical Engineers 1897.

Plate 91.

PROPELLER VENTILATING FANS.

Helical Blades.

24 - inch Fan

600 *revs. per min.*

Fig. 54. *Axial Velocity of Air.*

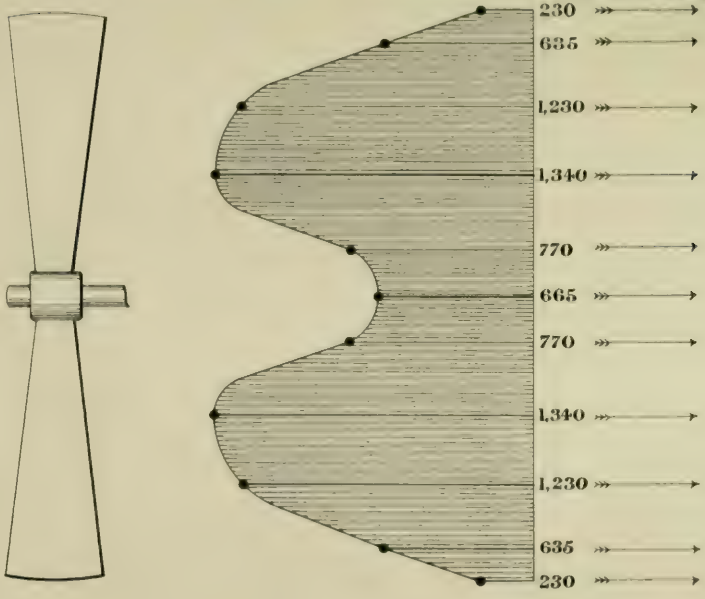
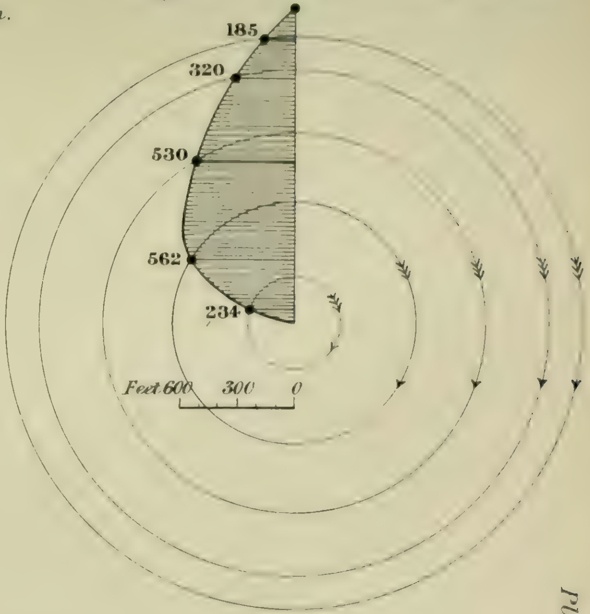


Fig. 55. *Rotary Velocity of Air.*



Figures denote
Velocity in feet per minute.
Scale 1/8th.

Plate 92.

PROPELLER VENTILATING FANS.

Fan arranged with thrust bearing.

Fig. 56.

Side Elevation.

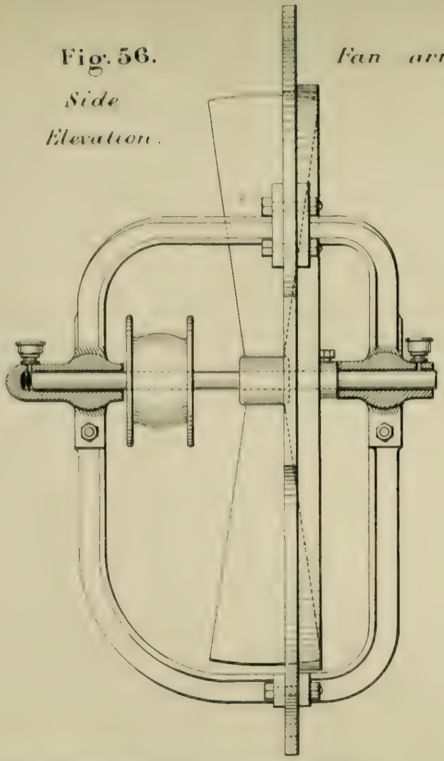
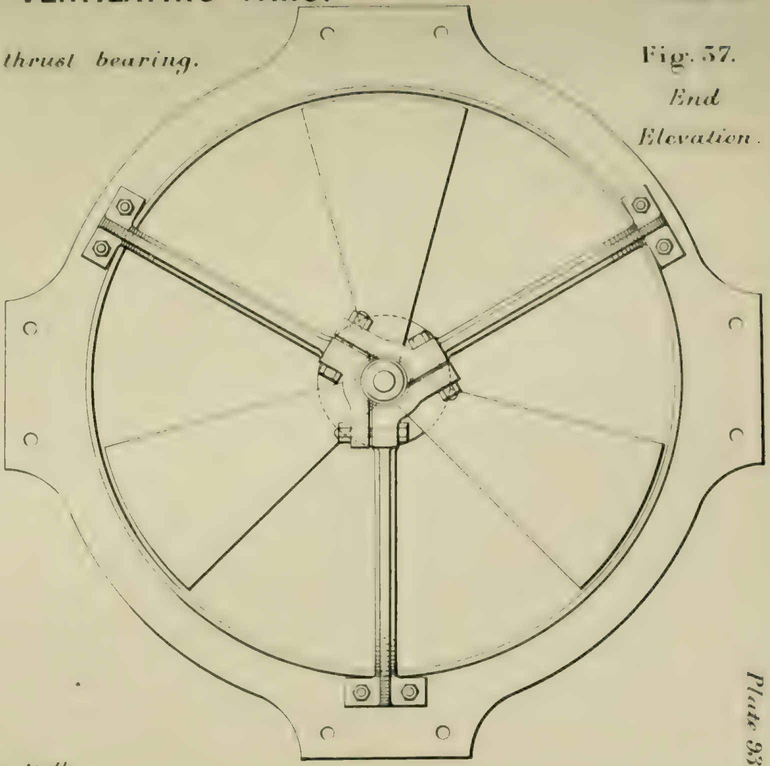


Fig. 57.

End Elevation.



Scale 1/8th.

Plate 93.

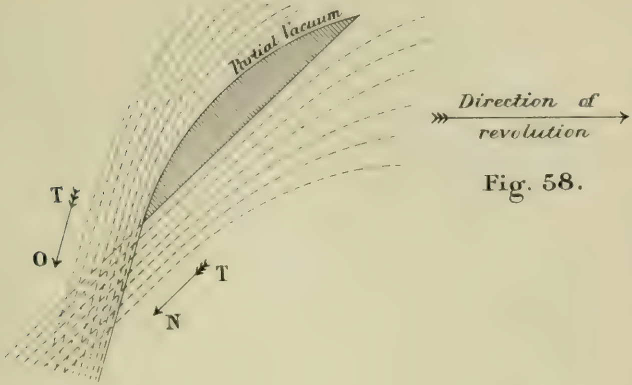


Fig. 58.

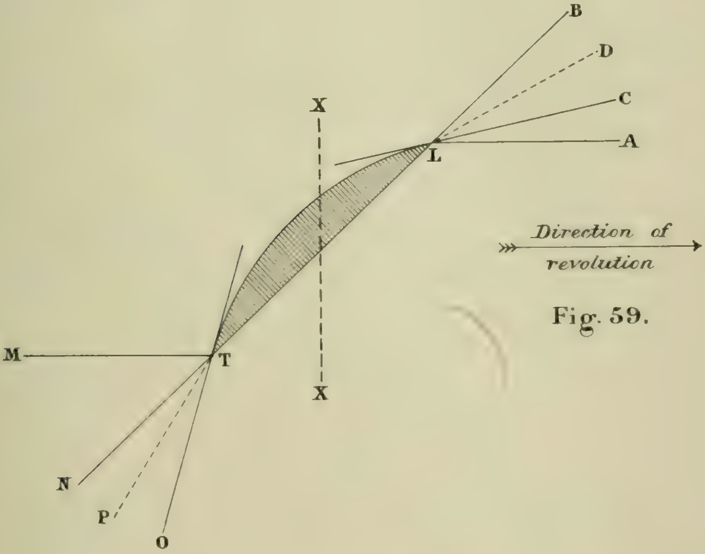


Fig. 59.

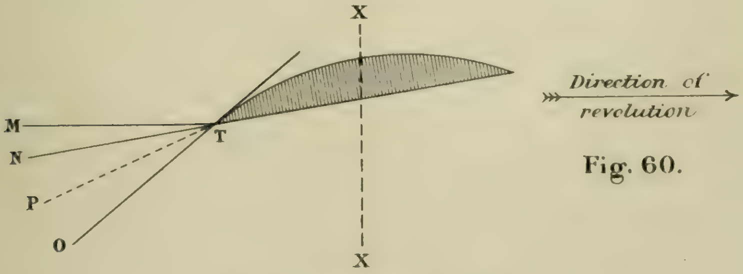


Fig. 60.

DIAGRAM ACCOUNTS.

Fig: 1. *Machinery Employment in 1897.*

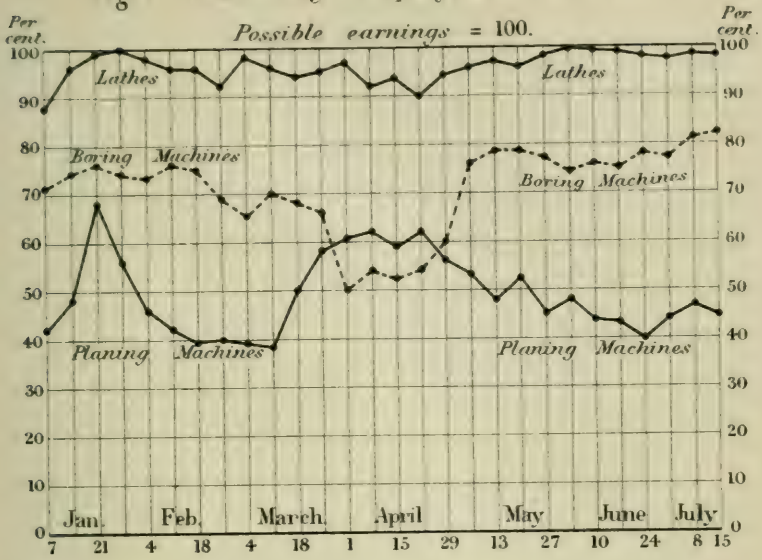


Fig: 2. *Nine Years' Work.*

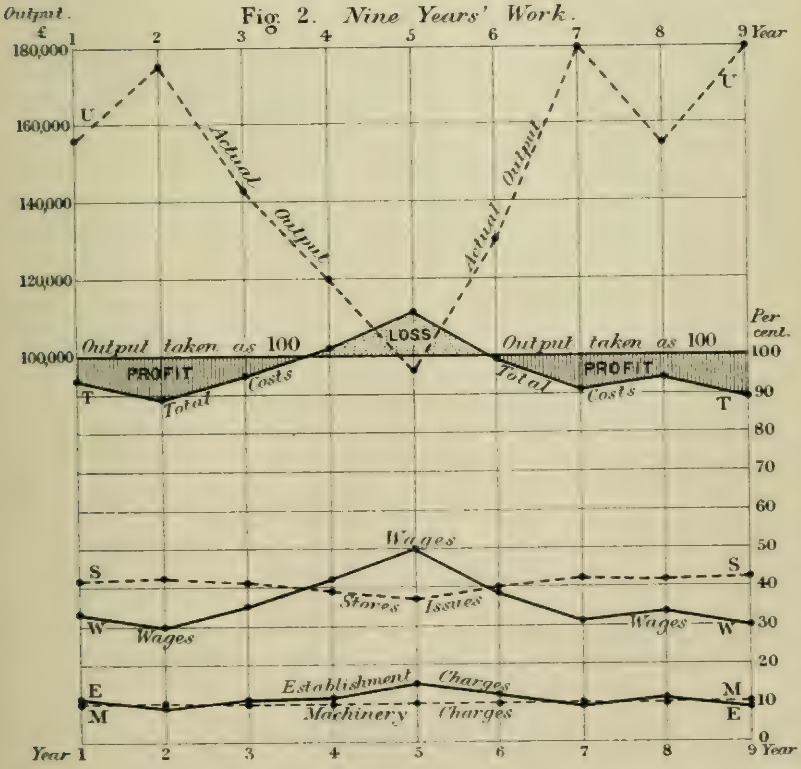


DIAGRAM ACCOUNTS.

Plate 96.

Fig. 3. *Eight Contracts in Bad year.*

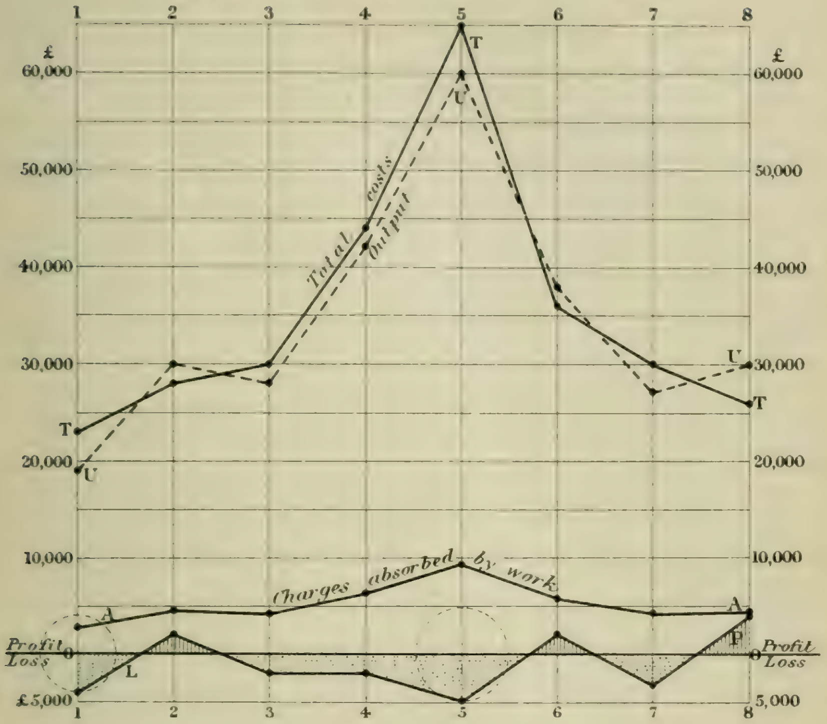


Fig. 4. *Five periods of Work.*

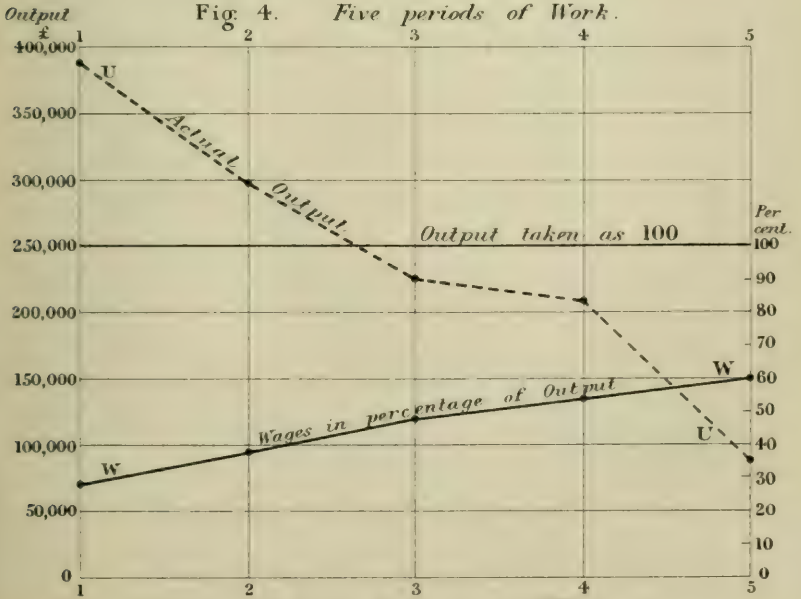


Fig. 5. *Twenty-nine Foundry Orders.*

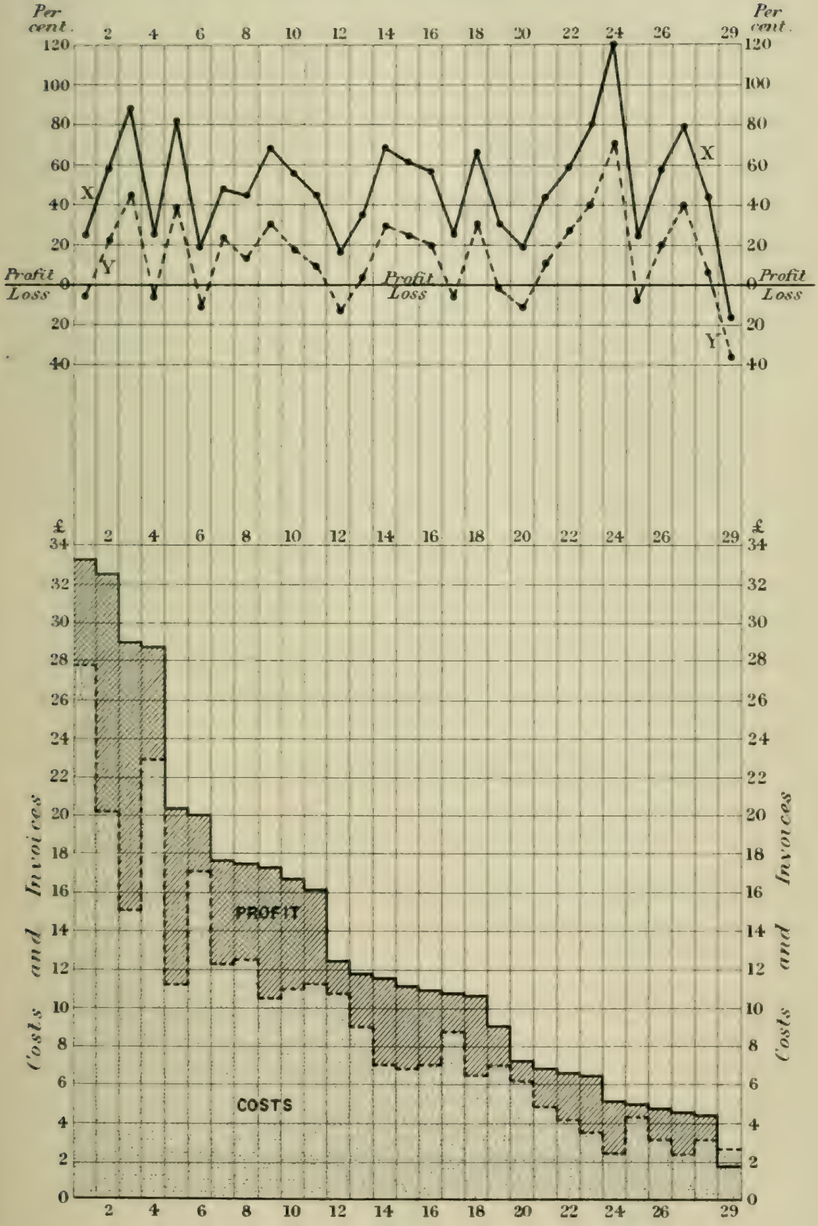


Fig. 6. *Quarterly Water Consumption.*

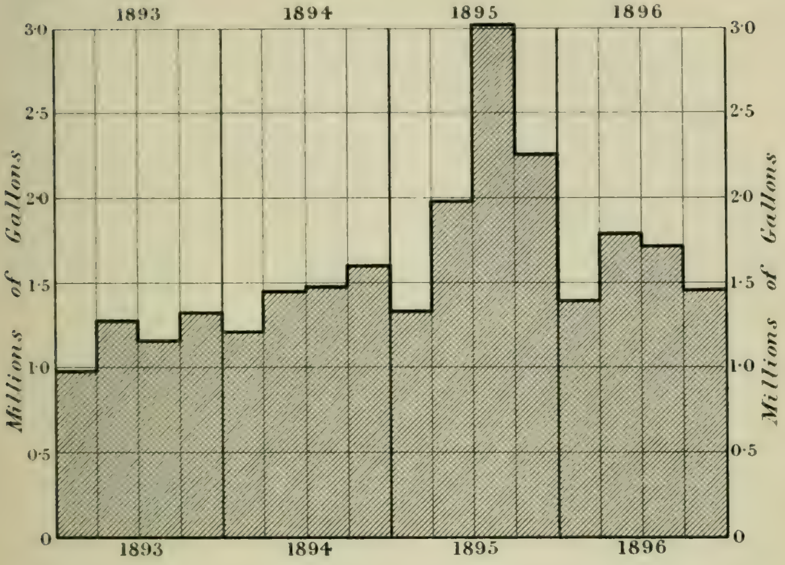
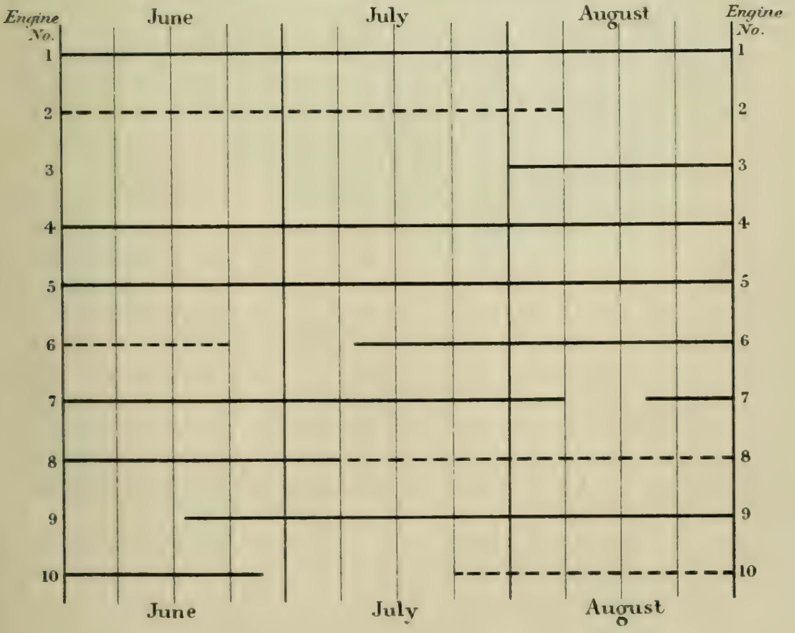


Fig. 7. *Condition of Locomotive Stock*



GEORGE STEPHENSON.

9 June 1781 — 12 August 1848.

First President, 1847–48.

Geo Stephenson

Facsimile of Signature to Minutes of General Meeting.
27 October 1847.

The Institution of Mechanical Engineers.

PROCEEDINGS.

JULY 1897.

The SUMMER MEETING of the Institution was held in Birmingham, commencing on Tuesday, 27th July 1897, at Ten o'clock a.m.; E. WINDSOR RICHARDS, Esq., President, in the chair.

The President, Council, and Members were received in the Examination Hall of the Municipal Technical School, Suffolk Street, by the Right Honourable the Lord Mayor, Councillor James Smith, and by the Chairman and Members of the Local Committee.

The LORD MAYOR had great pleasure in giving the members of the Institution of Mechanical Engineers a most hearty welcome to the City of Birmingham. The Institution he felt had contributed largely towards the material prosperity of the City. Mechanical engineering and the dependent branches of trade had been connected with Birmingham for the last hundred years. Birmingham had long been celebrated for its machinery, tools, and engineering appliances. Situated as it was in the midst of an iron and coal district, and aided by the skill of its workmen and the capacity of its manufactories, it had secured a large portion of engineering trade. There was another strong reason why this Jubilee meeting of the Institution should be held in Birmingham, namely that this was the birthplace of the Institution. Like many other organizations, political and otherwise, the Institution of Mechanical Engineers had started its life in Birmingham; and he understood that one of the Honorary Local Secretaries for the present meeting, Mr. W. Bayley Marshall, was only following his father who had been Secretary of the Institution many years ago, before the removal to London. All were anxious that England should maintain her reputation in making machinery. No Birmingham manufacturer liked to send to

America for his machines; and he hoped that in the near future the Members of the Institution would be able to supply all the varied requirements. The Institution he thought was doing a great deal for ensuring the future success of mechanical engineering. A special feature of its work was that of experimental research conducted by committees of its members. This he was sure must be the greatest help, not only to the members but to the general public. In Birmingham all were alive to the importance of the best training for students who intended to take up mechanical engineering; and the workshops and classes at Mason College and at the Technical School were doing much to give them the advantage of that training, which would be invaluable to them in after life. At present there were 700 students in the Technical School, who were studying subjects immediately connected with mechanical engineering. The fierce competition which manufacturers had to face could be met only by labour-saving machinery, in the production of which so many of the members of the Institution were engaged, and by developing the inventive genius of the people. The ingenuity of some of the machines now made was marvellous; they seemed almost human in their performance, except that they had no inclination to go on strike. The progress of the City of Birmingham depended largely upon its engineering works; and the citizens looked to the members of the Institution to develop and maintain the supremacy of their manufactures by supplying them with the best machinery. He had the greatest pleasure in giving the Institution a most hearty welcome to the City; and he hoped that the visit of the members would be not only enjoyable, but also instructive all round.

Mr. ARTHUR KEEN, Member of Council, and Chairman of the Local Committee, desired on behalf of the Committee to offer a hearty and sincere welcome to the members of the Institution. The Committee were determined to do all that they possibly could to make the visit of the members agreeable to them.

The PRESIDENT said it was indeed a great satisfaction to the members of the Institution of Mechanical Engineers to hold the summer meeting of their Jubilee year in Birmingham, the birthplace of the Institution; and the kind words of the Chief Magistrate of the City, and of Mr. Keen, the Chairman of the Local Committee, were especially gratifying. During the fifty years of the life of the Institution of Mechanical Engineers, he believed it had greatly contributed to the development of the science and the practice of mechanical engineering. The Lord Mayor could claim with pride and pleasure that no city in the kingdom had made greater progress than Birmingham in all that related to the highest aspirations of the times. No city had done more to improve the condition of the people, by raising and fitting them by education and example to attain the highest positions in the land. In expressing on the part of all the members present their gratification at the programme which had been arranged for this meeting, he could assure the Lord Mayor and the Local Committee that they intended to take the fullest advantage of their kindness and hospitality. They expected to look back upon this Jubilee meeting as one of the most pleasant and profitable they had ever enjoyed; and when they had accomplished all that related to the business portion of the meeting, they should gladly turn to the portion arranged for their pleasure and profit. It was the sincere desire of the Local Committee, as he well knew, that the meeting should be memorable in the annals of the Institution. On the part of all the members he thanked the Lord Mayor and the Local Committee for the hearty way in which the Institution had been received.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following sixty-five candidates were found to be duly elected:—

MEMBERS.

Adams, Edwin,	Manchester.
Adamson, Daniel,	Manchester.
Baker, George Samuel,	London.

Billetop, Torben Christian,	Newcastle-on-Tyne.
Chambers, Edward John,	Tipton.
Childe, Henry Slade,	Wakefield.
Clifford, Charles,	Dundalk.
Cox, Job,	Birmingham.
Fish, Sylvester Robert,	Lisbon.
Heaton, George,	Birmingham.
Hetherington, Edward Palmer,	Manchester.
Hiraoka, Hiroshi,	Tokyo.
Hirst, James,	Queensland.
Howard, Henry Fox,	London.
Hulse, Richard Lamplough,	Manchester.
Lambert, William Fraser,	Liverpool.
Lucy, Ernest Edward,	Wolverhampton.
MacDonald, David Johnstone,	Dundee.
Mills, William,	Sunderland.
Miyabara, Jiro, Captain I. J. N.,	London.
Monkhouse, Edward Wyndham,	London.
Newton, Thomas George,	Keighley.
Reid, Andrew Thomson,	Glasgow.
Reid, John,	Glasgow.
Richards, Henry William Hall,	Leicester.
Robson, George,	Auckland, N.Z.
Sharp, John,	Bolton.
Strickland, Frederic,	Dartmouth.
Turner, Alfred,	Birmingham.
Twelvetrees, Walter Noble,	London.
Vaux, Walter,	Bradford.
Wall, Charles Henry,	Birmingham.
Wearing, John Evenden,	Birmingham.
Whittell, Alfred Leighton,	Bombay.
Woods, Arthur Robert Thomas,	Liverpool.

ASSOCIATE MEMBERS.

Allen, Justin Edward,	Kew.
Bamber, Herbert William,	Meopham.

Cerrito, Frank Henry,	Birmingham.
Gordon, John Wilton,	London.
Grove, Harry,	Exeter.
Harwood, Robert Henry,	Calcutta.
King, Andrew,	Peterborough.
Larmuth, John Hamilton,	Manchester.
Leslie, William,	Calcutta.
MacIvor, Alexander,	Darwen.
Nakagawa, Goeokichi,	Tokyo.
Norton, Arthur,	Sheffield.
Phillips, Edwin Grant,	Madrid.
Price, Charles Graham,	Yokohama.
Rycroft, John Edward,	Bradford.
Scott, Herbert Kilburn,	Miguel Burnier.
Smith, Sidney,	Cape Town.
Stockton, Percy Sadler,	Loughborough.
Waynforth, Harry Morton,	London.
Welsh, John,	Johannesburg.
Worsley, Philip John, Jun.,	Birmingham.

ASSOCIATES.

Echevarri, Juan Thomas Wood,	London.
James, Albert Alfred,	West Bromwich.

GRADUATES.

Allan, Frederick William,	Glasgow.
Godson, Edward Harold,	Cheadle.
Guthrie, William James,	Troon.
Montgomery, Charles Hubert,	Horwich.
Rainforth, William Frederick,	Lincoln.
Robinson, Herbert,	Low Moor.
Wade, Francis Richard,	Chesterfield.

The President then delivered the following Address, reviewing the history of the Institution during the half century of its existence :—

ADDRESS BY THE PRESIDENT,

E. WINDSOR RICHARDS, ESQ.

GENTLEMEN,—The Institution of Mechanical Engineers, which in 1847 commenced in this city its life of usefulness, today revisits its birthplace to celebrate the Fiftieth year of its existence. Our first duty is to give expression to our high appreciation and grateful acknowledgments of the immense influence for good that has been exercised by Her Most Gracious Majesty, the Queen-Empress, throughout the sixty years of her glorious and beneficent reign, during which our Institution has so greatly prospered. On behalf of the Members the following address has been presented to Her Majesty:—

To Her Most Gracious Majesty THE QUEEN.

May it please Your Majesty,

We, the President and Council of The Institution of Mechanical Engineers, on behalf of ourselves and the Members generally of this Institution, humbly approach your Majesty to offer the assurance of our loyal and hearty congratulations upon the attainment of the Sixtieth year of your Majesty's reign.

We are deeply sensible of the wise and beneficent sway which your Majesty has throughout exercised over your Empire, and of the great advances consequently realised in Art and Science, particularly in Mechanical Engineering, to which this Institution, having been established ten years after your Majesty's accession to the Throne, has now been devoted for half a century.

We earnestly pray that your Majesty may still be spared to reign over a faithful and affectionate people.

In token whereof the Seal of the Institution has been here impressed, this 17th day of June 1897.

E. WINDSOR RICHARDS, *President.*

The following reply was received from the Home Secretary, the Right Honourable Sir Matthew White Ridley, Bart., M.P. :—

Whitehall, 26 June 1897.

I have had the honour to lay before the Queen the loyal and dutiful Address of The Institution of Mechanical Engineers on the occasion of Her Majesty attaining the Sixtieth year of her reign; and I have to inform you that Her Majesty was pleased to receive the same very graciously.

It may be useful, before referring to other matters, to recall to the Members the original objects of those who initiated our Institution, which were the following:—

To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the members of the Institution and to the community at large; and also to enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information upon such subjects.

Have we attained the objects for which the Institution was formed?

To answer this vital question it will be necessary for me to review rapidly for your consideration some of the work done by the Institution during the times of the several Presidents, and to give some brief notes on the origin and history of the Institution.

27 *January* 1847.—On Wednesday 27 January 1847 a general meeting was held at the Queen's Hotel, Birmingham, for the purpose of forming the Institution. Mr. McConnell, of Wolverton, occupying the chair, read a list of gentlemen who had sent answers to a circular inviting their co-operation and their consent to become Members of the Institution. On his proposal, seconded by Mr. Buckle, it was resolved "That the Institution be established, and composed of the gentlemen whose names he had announced."

Mr. Slate having read the Rules of the Institution, which had been prepared by a committee, their adoption was carried, on the motion of Mr. George Stephenson, seconded by Mr. Beyer.

Mr. McConnell moved the election of George Stephenson, as President of the Institution; and the nomination, having been seconded by Mr. Cowper, was carried with acclamation.

On taking the chair, the President gave an interesting account of his early days at Killingworth Colliery, where he began his career.

On the motion of Mr. John Henderson, Smethwick, seconded by Mr. Richard Peacock, the following were appointed to be the Vice-Presidents of the Institution :—

JOSEPH MILLER,	London.
CHARLES F. BEYER,	Manchester.
JAMES E. MCCONNELL,	Wolverton.

On the motion of Mr. Peter Rothwell Jackson, seconded by Mr. James Ward Hoby, the following were appointed to be the Council of the Institution :—

EDWARD HUMPHRYS,	London.
BENJAMIN FOTHERGILL,	Manchester.
JOSEPH RADFORD,	Manchester.
WILLIAM BUCKLE,	Soho.
EDWARD A. COWPER,	Smethwick.

On the motion of Mr. Beyer, seconded by Mr. Henry Chapman, it was resolved that Mr. Slate be Secretary and Mr. Maher acting secretary to the Institution.

Of the original Members who joined in constituting the Institution on 27 January 1847 the following two alone survive :— Mr. Peter Rothwell Jackson, and Mr. Richard Williams.

28 *April* 1847.—It was at the next meeting, held at the Queen's Hotel on Wednesday 28 April 1847, that the real work of the Institution was commenced by the reading and discussion of Papers, after the announcement of a donation of £100 from the President, and the reading of a concise list of subjects for papers, which even after

the lapse of half a century still retains its interest and suggestiveness. It ran as follows:—(1) the best form of railway axles and wheels; (2) the best description of engine and mill for manufacturing iron; (3) the best form of Barker mill or turbine; (4) the best form of luggage engine for narrow gauge; (5) the most economical stationary steam-engine with coal at 6*s*., 12*s*., and 24*s*. per ton, taken in a commercial point of view; (6) the best form of air-pump valves; (7) the best high-pressure marine boiler; (8) the best description of pumping engine for the thick-coal district of Staffordshire; (9) the flow of water through straight mains and curves.

17 *May* 1847.—The first paper published in the Proceedings, on experiments relative to the fan blast, by Mr. William Buckle, was read at a meeting at the Queen's Hotel on Monday 17 May 1847; and was followed by another upon the same subject by Mr. Edward Jones, of Bridgwater Foundry, Bridgwater.

27 *October* 1847.—The next meeting, held in the rooms of the Institution in Temple Buildings, New Street, Birmingham, on Wednesday 27 October 1847, is notable for the reading and discussion of three communications from the President, Mr. George Stephenson, who occupied the chair. The first was a description of a safety break invented by himself for railway carriages, of which he exhibited a model and drawing. The second was on the practicability of effecting a mechanical communication between the guards and engine-drivers of railway trains. The third paper from the President was on a steam indicator for marine and other boilers, invented by Mr. Sydney Smith, of Nottingham. Mr. Kintrea was appointed Secretary in 1847; but he resigned in October 1848, when Mr. W. P. Marshall was appointed Secretary, and remained in that position for twenty-nine years.

1848.—During 1848 and 1849 the meetings of the Institution were held in the Philosophical Institution, Cannon Street, Birmingham; and it was there that the President occupied the chair for the last time on Wednesday 26 July 1848, when his paper on the fallacies of the rotary engine was read and discussed. His death took place only seventeen days later, on 12 August 1848, at his residence, Tapton House, near Chesterfield, at the age of sixty-seven; and a notice of his life and character, prepared for the Council by Scott Russell, was read from the chair at the following meeting on 25 October 1848.

1850.—In 1850 a house was taken in Newhall Street, where for fourteen years afterwards the meetings were mostly held. At the first meeting held there, on 24 July 1850, the President, Mr. Robert Stephenson, M.P., was prevented from attending, in consequence of being engaged at the floating of the last tube of the Britannia Bridge. Mr. W. P. Marshall informs me that at this first period of the Institution it was very uphill work to maintain its existence; but thanks to the energetic support of the active members, including Beyer, Cochrane, Cowper, Fenton, Lloyd, May, McConnell, Ramsbottom, and Slate, none of whom are now left, steady though slow progress was made for a considerable time, and the Institution advanced every year. After 1864 the meetings were held in the Midland Institute, until the removal of the Institution head-quarters to London in 1877.

1856.—The proposal of holding the Summer Meeting of the Institution in the leading centres of engineering throughout the kingdom originated in 1856 with Mr. James Fenton, who was consulting engineer to the Low Moor Iron Co. from 1851 to 1863, and was at that time a member of the Council; and through his energetic exertions the proposal was realised in September of the same year, by a meeting held for the first time in Glasgow, under the presidency of Mr. Joseph Whitworth. As one result of this new step, the number of Members in the Institution, which for the seven preceding years had remained at almost a dead level of just over two hundred, now began at once to increase at a rate of growth which has since continued to progress steadily up to the present date, as shown by the annexed table and plotted in the diagrams, Plates 46 and 47. This meeting showed the engineers of Glasgow

Year.	Total Number of Members.	Annual Income.	Total Invested Capital.	Total number of Members and Visitors attending Meetings in the year.		
		£	£	Members.	Visitors.	Total.
1847	107	515				
1848	189	741				
1849	201	600				
1850	202	676				
1851	203	619				
1852	204	614				
1853	216	703				
1854	228	702				
1855	218	620				
Commencement of peripatetic Summer Meetings in 1856.						
1856	259	817				
1857	301	997				
1858	341	1,097				
1859	391	1,275				
1860	428	1,445				
1861	464	1,391				
1862	497	1,618				
1863	540	1,889				
1864	572	1,926				
1865	652	2,141				
1866	728	2,462				
1867	791	2,388				
1868	825	2,357	4,500			
1869	855	2,650	4,500			
1870	862	2,823	4,500			
1871	875	2,806	5,973			
1872	912	2,953	6,973			
1873	956	3,208	7,978			
1874	992	3,270	9,178	416	231	647
1875	1,018	3,471	10,188	434	203	637
1876	1,041	3,440	11,016	357	117	474
1877	1,075	3,641	11,869	521	168	689
Removal from Birmingham to London in 1877.						
1878	1,140	3,801	8,868	394	263	657
1879	1,178	3,782	8,868	441	314	755
1880	1,210	4,085	8,868	414	269	683
1881	1,276	4,248	9,217	485	279	764
1882	1,370	4,660	9,617	509	270	779
1883	1,440	4,690	10,617	397	189	586
1884	1,554	5,094	10,617	887	248	1,135
1885	1,640	5,330	11,967	607	362	969
1886	1,674	5,701	13,467	620	370	990
1887	1,741	5,753	15,469	554	260	814
1888	1,806	6,121	16,490	442	244	686
1889	1,858	6,260	17,489	418	246	664
1890	1,943	6,784	18,888	518	236	754
1891	2,077	7,212	20,287	628	273	901
1892	2,147	7,192	22,537	502	299	801
1893	2,157	7,030	24,787	426	265	691
1894	2,222	7,081	26,558	620	331	951
1895	2,271	7,274	27,340	546	363	909
1896	2,360	7,388	{18,102 {16,877}	488	334	822

and the neighbourhood their own numerical strength; and led to the establishment in the following year of the Institution of Engineers in Scotland, under the presidency of Professor W. J. Macquorn Rankine. The establishment of that Institution, and subsequently of various other engineering societies in different districts, is believed to have proved ultimately beneficial to the growth and prosperity of the Institution of Mechanical Engineers. The summer meetings have now been held at the following places during the last forty-two years:—Glasgow four times, Manchester four times, Newcastle three times, Leeds three times, Birmingham now for the third time, Sheffield twice, London twice, Liverpool three times, Dublin twice, Paris three times, Nottingham once, Middlesbrough twice, Penzance once, Cardiff twice, and once in Bristol, Barrow-in-Furness, Liége, Lincoln, Edinburgh, Portsmouth, and Belfast. In connection with the meeting at Portsmouth in 1892 the Council drew the attention of the Members to a feature which had been noted with much gratification, namely that the cost of the necessary arrangements was distributed among the Members for whose benefit they were made: thereby showing for the first time how the Members may be enabled to enjoy the advantage of visiting various localities, free from all misgivings of their visit assuming in any degree the aspect of a visitation. The same considerations clearly enlarge the range of localities in which future meetings of the Institution may advantageously be held.

Our first President, 1847–48, George Stephenson, is universally recognised as the "Father of Railways"; and this designation is itself so comprehensive that it need not be elaborated by any lengthy retrospect of his illustrious career. Simultaneously with Davy he invented a safety-lamp for collieries. On his decease in 1848 Scott Russell wrote of him:—"In our late president England has lost one of her most distinguished men, the world one of its great benefactors."

Robert Stephenson, F.R.S., President for four years 1849–53, took up and carried forward the railway work originated by his father.

He developed the construction of wrought-iron bridges for carrying railways across estuaries, rivers, and valleys: notably the High Level Bridge at Newcastle-on-Tyne, and the Britannia and Conway Tubular Bridges. The successful realisation of these original works has proved a lasting stimulus to the progress which has since culminated in so great an achievement as the Forth Bridge.

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55, has left a name associated with the Lancashire boiler, and with an extensive variety of general mechanical engineering work, on which he contributed and collected a large store of useful information.

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, made his name famous by working out a system of gauges and screw threads which speedily won its way into extensive practical use. He developed and matured machinery for accurately measuring by contact, instead of by sight. During his presidency in 1856 was announced the discovery by Henry Bessemer, which claimed that, by blowing cold air into and through molten metal, malleable iron and steel could be produced without fuel. This statement startled the whole engineering and metallurgical world, and was received by the manufacturers of wrought-iron with mingled feelings of panic and unbelief. The revolution was not brought about so quickly as was anticipated, owing to many practical difficulties; and it was soon found that iron containing phosphorus was quite unsuitable to the process. Several Members of our Institution threw all their energies into helping the solution of the many difficulties surrounding the carrying out of the invention. William Menelaus of Dowlais was one of the first to take up the manufacture on a large scale; also John Ramsbottom. Daniel Adamson successfully applied the ductile material to the construction of the boilers he did so much to improve, and thereby rendered practicable much higher pressures of steam. His vertical blast-engines for supplying air to the converters at 25 lbs. pressure, with metallic piston-valves, relieved the great trouble experienced by the constant failures of the india-rubber valves surrounding the air cylinders. The Galloways of Manchester; Benjamin Walker of Leeds, who constructed many Bessemer converting plants and all kinds of rolling-mill engines and machinery for home and abroad; William Richardson of Oldham, and many others, at once recognised the value of this homogeneous metal, and applied it to all purposes of construction for engines and machinery; and the results have proved the soundness of their early judgment. The production of Bessemer steel has now attained to a yearly quantity of nearly two million tons of ingots in Great Britain and of five million tons in America; and in connection with the really wonderful development of the process in America the names of Alexander Holley, William Jones, and John Fritz must be remembered. It is easy for us to forget the great troubles and difficulties experienced during the first fifteen or twenty years of the process, and the enormous exertions, the energy, the ability, and the determination of the venerated inventor in carrying out his great invention to a commercial success in a works established by himself and his partners in Sheffield, where at that time only about 50,000 tons of steel were produced annually. Sir Henry Bessemer is now in his eighty-fifth year, and his name is honoured amongst men in all countries, and his kind and generous heart makes him beloved by all who have the great privilege of his friendship. He may be justly proud that by his invention, conceived and matured during the reign of Her Most Gracious Majesty, the world is producing about 10,500,000 tons of Bessemer steel annually. He has said that these high figures do not adequately impress themselves on people's minds; and suggests that we picture to ourselves a gigantic armour plate, 100 miles long 5 feet thick and 20 feet high, as representing the output of steel every year by his process.

In 1866 Sir Joseph Whitworth was again elected President; and in 1875 he read a paper in Manchester on the hexagonal bore for rifles and guns, and on his method for compressing fluid steel for guns and other purposes, which with its discussion was one of the most interesting ever brought before the Institution.

John Penn, F.R.S., President for the four years 1858–59 and 1867–68, rendered his name in connection with marine engines a synonym for the highest standard of excellence both in design and in workmanship. He adopted and improved the oscillating engine, and introduced trunk engines for driving screw propellers in war ships. The use of wood bearings for screw-propeller shafts was introduced by him in 1854; and he was early in applying superheated steam in marine engines, and in adopting the plan of constructing boilers with flanged plates without angle-irons.

In 1867, during his second presidency, an important step was taken when it was decided to hold the Summer Meeting in Paris, that being the first occasion of an English Society holding its meeting abroad. The cordiality of the reception of the Institution was very great, and the meeting proved a complete success, largely due to the long and intimate connection of the President with the French Government in matters of marine engineering, and very largely due also to the tact and ability of the Honorary Secretary, Mr. Henry Chapman.

James Kennedy, 1860, is remembered in connection with the locomotives built by his firm of Bury, Curtis, and Kennedy. These included the first made in England with horizontal cylinders applied direct to the crank-axle of the driving wheels; the same engine in conjunction with a tubular boiler was distinguished by a vertical cylindrical fire-box surmounted by a capacious dome; the latter characteristic feature was adhered to in many subsequent engines with a view to mitigating the trouble of priming. The engines employed at the opening of the London and Birmingham Railway were built at his works, from which were also sent to America from 1832 to 1834 a number of locomotives. He also constructed marine engines for the early Cunard steamers.

Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62 and again in 1869, commenced his engineering career with the application of water-pressure to the transmission of power; and through the subsequent invention of the accumulator, his hydraulic machinery and the construction of the Elswick Works for the manufacture of guns &c., developed into lasting monuments to his fame. As far back as 1802 Bramah had applied water-pressure to cranes for raising and lowering goods; but the practical development of the principle awaited the advent of the accumulator.

Robert Napier, 1863–65, is identified with the steady and continuously increasing development of shipbuilding and marine engineering. In 1839 he joined in establishing the famous Cunard line of mail steamers between this country and North America.

John Ramsbottom, 1870–71, besides improving with permanent advantage the general design of locomotives, introduced among their details more than forty years ago his well-known piston with its simple packing-rings, and his admirable safety-valves which could not be tampered with. Shortly afterwards he devised the plan for locomotives while running to pick up water from a trough laid on the permanent way. The high-speed cotton-cord traversing-crane; the reversing rolling-mill, the horizontal duplex steam-hammer, and the manufacture of weldless steel tires from conical ingots, also originated in his sound inventive ability. His idea of reversing the engines of rolling mills, and so avoiding the old arrangement of five wheels and reversing clutch with fly-wheel, proved highly valuable. A pair of 30-inch cylinders, geared about 2½ to 1 to the rolling mill, was easily reversed, and served remarkably well for cogging heavy ingots and for rolling ship and boiler plates; but for rails, which were being rolled in ever-increasing lengths reaching 160 feet, the gear was found slow and noisy, and was discarded in favour of engines having cylinders as large as 60 inches diameter and 5 feet stroke, which were applied direct to the rolls with excellent results. For rolling heavy plates the geared system is highly efficient, and is probably the best; but for rails in 160 feet lengths, and for billets 300 feet long, direct rolling is absolutely necessary. In America the three-high train for rolling backwards and forwards was long ago adopted and is still in use; and it is found so efficient that at a rolling mill at Chicago, and also at the Edgar Thomson works, over 8,000 tons of rails per week have been regularly produced by this method. Besides being a Past-President, Mr. Ramsbottom had been one of the original Members who joined in constituting the Institution at its establishment on 27th January 1847; and on the occasion of his recent decease, which took place on the 20th May last, a letter of sympathy from the Council was addressed to his family.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73, whose name is associated with that of his brother Frederick as inventors of the regenerative system for melting iron and steel, read a paper in Birmingham in July 1862 on the gas furnace. In 1862 he showed models of the gas producer and regenerative furnace in the Exhibition in London, to which my attention was called by Dr. Percy, who was much interested in them and anticipated great results from the invention; but no one could possibly have foreseen the really marvellous developments brought about by this invention, by which the processes of steel-making, known as the Siemens or ore process and the Siemens-Martin or pig and scrap process, were made possible. The world was thus given a material, wonderful in ductility and in uniformity of quality, which can without exaggeration be described as magnificent. At the time of his presidency of this Institution twenty-five years ago, the production of Siemens-Martin steel was 40,000 tons for the whole of 1872, and the price of ship plates about £17 per ton; whilst last year the production in Great Britain had reached nearly 2,354,000 tons, the price of ship plates being brought down to £5 5*s.* to £5 10*s.* per ton. The total production of open-hearth steel in all countries in 1896 was nearly seven million tons. In 1879 the quantity of ship plates made by this process was 20,000 tons, as compared with 9,000 tons made by the Bessemer process; and it was at that time predicted that open-hearth steel would take possession of the field for ship and boiler plates, while the Bessemer process would supply the great bulk of the material required for railway purposes. It would appear as if this prophecy would soon be realised, for we find that in 1896 the production of plates and angles by the Siemens process was about one million tons, and by the Bessemer about 60,000 tons; while by the Bessemer about one million tons of rails were made, and by the Siemens 40,000 tons.

Sir William Siemens' name is closely associated with the invention and evolution of modern dynamo-electric machinery, which practically abolished the use of permanent magnets, rendering possible the great advances that have since been made in electric lighting and transmission of power. In 1887 he suggested the utilization of the vast power of Niagara Falls for the purpose of generating electricity, transmitting it to long distances, and retransforming it into motive power.

In connection with the manufacture and laying of the submarine cable between Malta and Alexandria in 1860 he devoted much consideration to the design and construction of special machinery for the manufacture of such cables, and also to the improvement of all forms of telegraph apparatus.

Sir Frederick Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75. This eminent engineer, during a long and useful life, has done very much to further the interests of our Institution; he is one of the most popular of our members, his presence at the meetings is always welcomed, and his utterances are always instructive.

He has done good service in strongly advocating thrift and the husbanding of our coal resources. In 1872, at the Liverpool meeting, he read a paper on the progress effected in economy of fuel in steam navigation. In August 1874, in his address at the Cardiff meeting, he strongly directed attention to what he correctly termed the cruelly and wickedly wasteful manner in which we were rapidly using up the principal source of the wealth and power of the country, namely coal. At that time 120 millions of tons were being raised yearly in the United Kingdom, and today nearly 200 millions. These grave words of warning did not receive the attention they deserved, and he could repeat them today with even greater emphasis; but I fear no words of warning, however clearly and solemnly they may ring out from even this great and observant authority, will avail with those who work collieries "with no other object than that of obtaining the utmost present profit out of them." But I shall do well to repeat on this occasion his words of twenty-three years ago:—"It becomes us mechanical engineers to do all that lies in our power to cause all to respect and to understand the value of that which they have but too long lightly treated and grossly abused."

Thomas Hawksley, F.R.S., 1876–77, whose name is associated with the supplies of water and gas to towns, was probably the greatest authority of his time on those matters. During his presidency the head-quarters of the Institution were removed from Birmingham to London.

At the Summer Meeting held in Bristol in July 1877 in his presidential address he took a gloomy view of the relations existing between employers and employed, asserting that our labour was too dear for successful competition with foreign countries, too dear in respect of the quantity of work performed, and too dear in respect of the obstructions and restrictions which the modern workman thinks fit to place upon his employment and employer. After a lapse of twenty years these words seem even more applicable to the present state of these relations than they were at the time they were uttered.

Mr. John Robinson, 1878–79, in addition to being identified with the construction of locomotive engines for all quarters of the globe, is remembered also as having introduced the practical and extensive use of the Giffard injector.

In June 1878 the Institution paid its second visit to Paris, and this was again most successful, instructive, and enjoyable; and the President bore testimony to the valuable services of Mr. Henry Chapman, who acted as Honorary Secretary to the meeting. In compliment to the Institution, the Société des Ingénieurs Civils de France elected the President to the Honorary Membership of the Society; and he was also made a member of the jury for deciding upon the awards for engineering excellence in the exhibits at the Exposition Universelle of that year.

On the recommendation of the President in 1879, the Members passed a resolution that a Research Committee should be established for the investigation of unsettled mechanical questions. This formed an important expansion of the work of the Institution, which has now engaged in practical and experimental research into various subjects of Mechanical Engineering, including the strength of riveted joints, the hardening and tempering of steel, friction at high velocities, marine-engine trials, the value of the steam-jacket, gas engines, and the effects of alloys.

Edward A. Cowper, 1880–81, was one of the pioneers of this Institution. He took up early the Siemens regenerative system, and developed its application for heating the air for blast furnaces, and thereby not only largely increased the output of the furnace, but effected an economy of nearly 2¼ cwts. of coke per ton of iron made over the cast-iron pipe stoves then generally in use. He also devised the intermediate receiver or "hot pot" for compound engines.

Mr. Percy G. B. Westmacott, 1882–83. His name is associated with that of Lord Armstrong in the development of the Elswick Works, and in the construction and working of hydraulic machinery on a large scale.

In 1883 the Summer Meeting was held in Belgium, invitations having been received from the municipalities of Liége and Antwerp. His Majesty the King of the Belgians, as a mark of honour to the Institution, commanded the attendance of the President at the Palace. The very important works of Angleur, Ougrée, Schlessin, and the collieries of Mariemont were visited; and also the works of the Société John Cockerill, the most important engineering and iron and steel works in that industrious kingdom. The members were cordially received and hospitably entertained, and the Meeting was altogether a most successful one.

Sir Lowthian Bell, Bart., F.R.S., 1884. This distinguished chemist and metallurgist and most indefatigable worker combined the heavy responsibilities of conducting the various duties of the management of his extensive collieries, ironstone mines, and several blast-furnaces, with parliamentary duties, and all the labour such duties involve. Besides being a director of the North Eastern Railway, which serves with much advantage the great industrial districts of Durham and Cleveland, he was at the same time director of extensive steel works; and yet he devoted many years of experimental research and study to the intricate problem of the chemistry of the blast furnace, and of its working. The results of these researches and sound reasoning he has given freely to the world. His presidential address at the Cardiff meeting, and his many contributions to the discussions at the meetings of the Institution have been of exceptional interest and value.

Mr. Jeremiah Head, 1885–86, became a Member in 1859 and Member of Council in 1874. He has given much time and consideration to all that concerns the well-being of the Institution, in which he has taken an active interest. He has contributed several papers on mechanical and metallurgical subjects, and has frequently taken part in the discussions. In his presidential address at the Lincoln meeting he gave an account of the gradual displacement of iron by steel for very many purposes. On the visit of the Institution to Middlesbrough in 1893 his services were exceptionally valuable. His paper on that occasion upon the iron and steel industries gave the best description that has yet been written of that remarkable district.

Sir Edward H. Carbutt, Bart., 1887–88, has always shown great interest in the well-being and prestige of our Institution, and in mechanical engineering generally. He greatly improved the details of the Nasmyth steam hammer, and by its enlargement contributed to the means of supplying the constantly increasing demands for heavier machinery. In the House of Commons he was recognised as an authority on railway, engineering, and ordnance questions. He was appointed a member of the Government Committee, and urged the necessity for the extension of railways in India. He was also a member of Lord Morley's Committee, which was nominated through his representations for the re-organization of the workshops of the War Department.

Mr. Charles Cochrane, 1889, has worked for many years to improve blast-furnace practice. He largely increased the capacity and production of his furnaces, and reduced the quantity of fuel used per ton of pig-iron. He was one of the first to recognise the advantages of regenerative fire-brick stoves for heating the blast, and was greatly instrumental in making them successful; their introduction required a large expenditure of money, much perseverance, and an intimate knowledge of blast-furnace work. His contributions to the Institution upon blast-furnace construction and management, and the discussions thus raised, have been of great value to blast-furnace metallurgists generally.

In July 1889 the Institution visited Paris for the third time, and was most cordially and hospitably received by the President, M. Eiffel, and the Members of the Société des Ingénieurs Civils. Several works were inspected. Mr. Cochrane as President expressed grateful appreciation of Mr. Henry Chapman's valued services to the Institution. We hope that those services will for the fourth time be asked for and given to the Institution in 1900.

Joseph Tomlinson, 1890–91, was an enthusiast in all things concerning locomotives, and was intimately acquainted with their construction from almost the earliest days. When locomotive superintendent of the Taff Vale Railway he succeeded in 1858 in using coal in locomotive fire-boxes. His subsequent reorganization of the engineering department of the Metropolitan Railway was signalised by raising that undertaking to the prosperity it attained as the result of his successful efforts. He took an active leading part in the conduct of the friction experiments carried out by this Institution.

Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93. To him is due the credit of the organization of the Alloys Research Committee of this Institution, whose investigations have already given us most interesting papers and discussions, the practical value of which will ere long be demonstrated. His present distinguished post at Woolwich, as the first civilian engineer entrusted with the entire control of the Ordnance Factories, which he conducts with signal ability and with great advantage to the nation, is highly gratifying to all the members of our Institution.

Professor Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95, Emeritus Professor of Engineering in University College, took up the subject of riveted joints for a Research Committee of the Institution, and carried out an exhaustive series of experiments up to the limits of the strength of the most powerful testing machines in this country. In connection with a Research Committee he also originated and carried out and recorded in the Proceedings a set of marine-engine trials on a practical scale, such as had never before been attempted; and the success realised has resulted in revolutionising the views previously entertained as to the proper conduct of trials of this kind. As an early worker in connection with electric lighting and electric power supply, he has designed and carried out works for these purposes for many of the leading municipalities in the kingdom; and more recently has added to these responsibilities that of directing the electric working of a metropolitan line of railway. His presidency witnessed the initiation of the steps requisite for the building of the house now in course of erection for the Institution.

To complete the list of the half-century of Presidents, it is necessary that I should add the name of Edward Windsor Richards, 1896–97. All that need be said of him is that he greatly desires to be of service and to further the interests of the Institution. He has the earnest hope and belief, that, when the Centenary is celebrated, the then president will be able to congratulate the members on the progress made in the second half of the century, and that it will be as great or greater than that in the first half, and that the home building at this time for the purpose of drawing the Members into closer companionship will have greatly contributed to that increased success.

The Institution House is now making rapid progress, and the architect holds out the hope that the lecture theatre will be available for the next Spring Meeting. The Finance Committee have reported to the Council that the 250 debentures for £25,000 have been allotted to the seventy-five applications received, the amount applied for having been £52,700.

The Council have addressed letters of congratulation to the following Members of this Institution upon the honours conferred on them by Her Majesty:—Sir Alexander Wilson, Bart.; Sir Lindsay Wood, Bart.; Sir John Wolfe Barry, K.C.B.; Sir Alexander R. Binnie; Sir Benjamin A. Dobson, Member of Council; and Sir Thomas Richardson, M.P.

We have about 10,000 volumes in the Library, and our Proceedings fill 50 volumes; we exchange Transactions with 103 societies, 47 inland and 56 foreign; we present 53 volumes annually to 26 colleges and libraries, making a total of 156 volumes.

Although this review of the work of our Institution has been rapidly and briefly sketched, it is sufficient to prove that we have carried out the objects for which the Institution was formed; and we can justly claim that we have contributed largely to the general happiness and material prosperity, not only of the people of Great Britain, but of the whole civilised world. Although we have reached our Jubilee year, we are still in our youth, full of vigour, full of hope, and full of determination to keep abreast with all progress affecting our profession.

Mr. RICHARD WILLIAMS had great pleasure in proposing a vote of thanks to the President for the able, interesting, and exhaustive Address to which they had just listened. He did so however with some diffidence; for, although he had been a member of the Institution from its birth fifty years ago, and had attended most of the early meetings, he had never before been called upon to make a speech. This was therefore practically his maiden speech: say his old-maiden speech. Under these circumstances he thought he might claim from the members those indulgences which were generally conceded to young beginners. The President had kindly referred to himself, and to his old-fashioned position as an original member of the Institution. He greatly regretted to find that no others were now able to be present of those who like himself had witnessed the very beginning of the Institution, when, so to speak, it was an infant "mewling and puking in the nurse's arms." With a feeling of melancholy he realised that he was now like "the last rose of summer left blooming alone." Especially should he have liked to see present the former secretary of the Institution, Mr. Marshall. Along with some of the older members he well knew that to no one did they owe so much in the early life of the Institution as to him. Unfortunately he was now an invalid, otherwise he was sure he would have been present, and would have given to himself that support which as an old man he felt he needed. It had been his own good fortune to hear the first President, George Stephenson, and he had also heard his son Robert. In his memory they were both as vividly present to him now as they were when they addressed the Institution in its early days. So also were the long roll of eminent engineers who had since had the honour of addressing the Institution as Presidents, an honour which had re-acted upon the Institution itself. George Stephenson was unquestionably the most distinguished engineer of his day. He had peculiar methods and peculiar ideas, which he expressed in peculiar language; but they were eminently engineering ideas, and specially calculated to give vitality to the Institution. In the Address to which the members had just listened, he was sure they had all been gratified by the graphic review furnished by the President of the progress made by the Institution. Although it had been growing for fifty years, it had not yet, according to the President's representation, arrived at maturity. He had himself seen it in its infancy: he should never see it in its full maturity, for he believed it would long continue to grow. The numbers recorded by the President clearly proved that the Institution was exceedingly popular, and that it was still growing in popularity. When he knew it at first it was but as a mustard seed; it was now a great tree spreading its branches wide over the engineering world. There were now members of the Institution in almost every foreign country; and he believed that the membership would continue to extend under the influences dealt with in the Address which had just been delivered, and would add to the vigour, the life, the dignity, and the usefulness of the Institution. He therefore asked the

(Mr. Richard Williams.)

members to give to their President, Mr. Windsor Richards—whose name was familiar in the mouths of engineers as household words, and was that of a man who had added lustre to the Institution—their most hearty thanks for the Address which he had delivered.

Sir EDWARD H. CARBUTT, Bart., Past-President, seconded the vote of thanks so ably proposed by their oldest member, Mr. Richard Williams. He had had the pleasure and honour of knowing the President nearly all his life. From his earliest youth upwards he had been devoted to engineering: and had always kept a record of everything that he did. Not only for engineering had he worked hard, but also during his presidency for the Institution of Mechanical Engineers; and he was sure therefore that the members would cordially support the vote of thanks which had been proposed.

The PRESIDENT considered it both a privilege and an honour that the vote of thanks just passed should have been proposed by Mr. Richard Williams, who had known the Institution during the whole period of its existence. He felt highly flattered by the cordial manner in which the proposal had been made and seconded and received by the members. He heartily thanked them for their encouragement, and for the kind reception they had given to his Address.

The PRESIDENT said the announcement made from the chair a year ago at the Belfast meeting, respecting the serious illness of the Secretary in consequence of over-work, might perhaps have prepared the members for learning that he had now felt himself compelled to resign his position as Secretary of the Institution. As they all well knew, Mr. Bache had been a faithful servant, and had done all he possibly could for the interests of the Institution. Last summer his health had given way under the stress of that work. After the Belfast meeting, in the hope that his health and strength would be renewed, the Council had wished him to take six months' holiday, during which they had desired him to do no work, or as little as possible. On resuming his duties at the office however, he had felt that his vigour and energy had been so far impaired as to preclude his resuming the full amount of work and responsibility of which his illness had been the result. The matter had been most carefully considered at several meetings of the Council, and the view was taken that it was necessary that they should continue to have an energetic secretary, seeing that they were about to move into a new house, and that there would consequently be a good deal to do in the way of re-organization: so that it was necessary to have a secretary as full of vigour and energy as possible for carrying on the business of the Institution. Accordingly the Council had concurred in Mr. Bache's view of the interests of the Institution, and with very deep regret had accepted his resignation. It then became necessary to consider what should be done for him; and they had referred back to see what had been done in the case of Mr. Marshall when he retired after twenty-nine years' service of the Institution. No doubt many of the members would recollect that at the end of 1877 an honorarium of Three thousand pounds had been given to him; it had been thought better to give an honorarium of that amount rather than any annual pension, and in that way they had wiped off the obligations of the Institution to the former Secretary. At that time there were 1,075 members on the roll: today there were 2,400 members, and the Council thought that they could not do less than offer Mr. Bache a similar honorarium of Three thousand pounds, as an acknowledgment of the value of the services rendered by him to the Institution over a period of forty-three years. It was necessary that the consent of the members should be asked to this arrangement; and he would put it in the form of a resolution:—"That the members approve of the action of the Council in presenting an honorarium of Three thousand pounds to Mr. Bache, and greatly regret that his illness prevents his continuing as Secretary of the Institution." He would ask some one in the body of the hall to second the resolution.

Several Members rose to second the resolution, and there was a cry of "We all second it."

Sir JOHN SMITH, having been a member of the Institution for nearly thirty-eight years, had great pleasure in being present on this occasion after a long illness, and in seconding the resolution that had been proposed. He well remembered the retirement of Mr. Marshall, who had formerly held the position which Mr. Bache had been holding for so many years; and when he retired from that position he had left behind him one who had hitherto carried out the duties of the office to the best of his ability, and he believed to the satisfaction of the members of the Institution. The present Secretary had always been courteous in manner, and had done everything he could for the members. He had therefore great pleasure in seconding the resolution that the honorarium proposed should be presented to Mr. Bache on his retirement from office.

Mr. JOSEPH ADAMSON was extremely sorry that Mr. Bache should be in such a state of health as no longer to feel able to act as Secretary of the Institution. When he was first appointed there had been some doubt as to whether he would be able to carry out the duties of his office; but he believed the members were now all agreed that those duties had been amply fulfilled. The only thing was that he had been too anxious to have everything done so carefully. He had much pleasure in supporting the resolution.

The resolution was unanimously adopted.

The PRESIDENT said the Council had advertised for a Secretary, and had already received many applications; others could still be received until the end of August. Early in September the Council would examine the qualifications of the applicants; and, having selected the one they thought best, would make a recommendation to the following meeting for the election by the members.

Mr. ALFRED BACHE, having been absent during the discussion respecting his retirement, said he was greatly obliged to the members for their kindness in passing the resolution which the President had communicated to him. Of course it would be a very severe wrench to tear himself away from what had been the work of forty-three years of his life. During the last fourteen years in particular it had been an extremely happy work, and he hoped that his connection with the Institution would always continue as long as life endured; certainly memories would, and he trusted friendships also.

The President said the members were aware that for many years the Institution of Civil Engineers had opened their rooms for the meetings of this Institution, and that the greatest courtesy had always been met with from every one connected with that Institution. To the late Secretary, Mr. Forrest, they were deeply indebted, as he had always been most courteous and kind to this Institution, and had done everything he possibly could to help them. On his retirement from the office of Secretary owing to ill health, the Council in remembrance of his unfailing courtesy had wished to present him with a testimonial, and had voted Fifty pounds for the purpose. Mr. Forrest had written expressing his thanks for the action of the Council. The members he was sure would agree that such a testimonial was well deserved at their hands; and he would ask them now to signify that they approved what the Council had done.

The approval of the meeting was given by show of hands and by applause.

The following Papers were then read and discussed:—

"Some points in Cycle Construction;" by Mr. F. J. Osmond, of Birmingham.

"The City of Birmingham Corporation Water Works;" by Mr. Henry Davey, Member of Council.

Shortly before One o'clock the Meeting was adjourned to the following morning.

The ADJOURNED MEETING was held in the Municipal Technical School, Suffolk Street, Birmingham, on Wednesday, 28th July 1897, at Ten o'clock a.m.; E. WINDSOR RICHARDS, Esq., President, in the chair.

The following Paper was read and discussed :—

"High-Speed Self-Lubricating Steam-Engines;" by Mr. ALFRED MORCOM, of Birmingham.

The remaining Papers announced for reading and discussion were adjourned to a subsequent meeting.

The PRESIDENT proposed the following Votes of Thanks, which were passed with applause :—

To the Committee of the Municipal Technical School, for their obliging invitation to the Institution to hold the present Meeting in the School, and for the facilities so kindly afforded for the occasion.

To the Council of Mason University College, for their similar obliging invitation to meet in the College.

To the Right Honourable the Lord Mayor of Birmingham, and to the Worshipful the Mayors of Coventry, Stratford-on-Avon, Walsall, and Wolverhampton, for their kindness in receiving and welcoming the Members in their visit. Also to Mr. Alfred Herbert, Mr. George H. Morley, Mr. P. A. Forbes, and Mr. W. H. Waister, for their obliging exertions in arranging the visits to these neighbouring Municipalities; and to Mr. Alfred Herbert for his hospitable invitation in connection with the visit to Coventry.

To the Proprietors of the numerous Engineering and Manufacturing Works and other Establishments, visited by the Members, for their kindness in opening their Works during the Meeting.

To the Local Committee—especially to the Chairman Mr. Arthur Keen, to the Honorary Secretaries Mr. W. Bayley Marshall and Mr. Eric M. Carter, and to their active co-adjutors on the Executive Committee—for the attractive programme they have prepared for the Meeting and Excursions, and for their hospitable invitation of the Members to their Conversazione.

To the Local Superintendents of the Railways, for the very efficient train accommodation they have so obligingly arranged.

The Meeting then terminated at Half-past Twelve o'clock. The attendance was 405 Members and 75 Visitors.

SOME POINTS IN CYCLE CONSTRUCTION.

BY MR. F. J. OSMOND, OF BIRMINGHAM.

The rapid development of the modern Bicycle is mainly if not entirely due to the influence of the racing track in securing the extinction of the least fit. The advance has been made by a lengthy and expensive process of trial and error; but this process would have been far more tedious and expensive, if it had been left to the judgment of the average rider to decide what constituted fitness. It is in the final struggle at the end of a well-contested race that the fine shades of difference in the speed of machines have been discriminated. This method of experiment may eventually give place to others more scientific and more exact; but the latter are hardly likely to be so popular.

It is now generally understood that the property of speed, possessed in such various degrees by cycles, is mainly a negative property: that is, it is the absence of any means of dissipating the energy transmitted through the mechanism; in fine the whole question is one of efficiency. The best machine both for racing and for ordinary riding is that which is most efficient. The principal causes of inefficiency in a cycle are—want of rigidity, and friction: a cycle which should be absolutely rigid and entirely without friction would have an efficiency of 100 per cent.; that is to say, it represents an ideal perfection which could not be exceeded, and cannot actually be attained.

Rigidity.—Of these two sources of inefficiency, it is probable that want of rigidity is the most important. It is in this particular that cycles differ far more than in friction; and it is invariably found that the more rigid machine is also the faster. The cause is twofold.

Firstly, the work done in springing the frame out of shape at each stroke of the foot is not spent in driving at the end of the downstroke, but only in lifting the foot at the beginning of the upstroke. The amount of exertion wasted in this way may be fairly estimated by sitting on a machine with the wheels fixed, and alternately applying and relieving the pressure of the foot on the pedal: the more springy the machine, the greater will be the fatigue experienced. Secondly, the springing of the frame causes a general condition of instability, due partly to the alteration of the balance through lateral movement of the pedals, and partly to the wheels being forced out of line, thereby causing the machine to swerve from side to side, instead of running a true course. Although the loss of efficiency from this cause may seem slight, the sense of instability has a disastrous effect in marring a sudden effort or in aggravating a steep hill.

Friction.—In a machine with well-constructed bearings, friction is mainly due to the chain. The consequent loss has been variously estimated; as low as 1 per cent. of the total power has been recently given. If this were correct, chain driving would be the most efficient means of transmitting power at present known. Probably however the loss was measured when the chain was not doing any work, which would make the test fallacious. About 5 per cent. seems nearer the truth. The means of avoiding these various sources of inefficiency may be considered in detail; and at the same time the means by which the ordinary stresses in a vertical plane may be met with a minimum of material.

Factor of Safety.—It has been said that the factor of safety for a cycle frame is about 1¼. If this is understood to mean that a machine designed for a 12-stone rider should not be ridden by one exceeding 15 stone, it is probably not far out in most cases; yet a well built frame will carry a steady load of at least ten times this weight without injury. The difference between these two statements is due to the fact that the front part of the frame is exposed to shocks which must cause bending stresses near the head H, Fig. 1, Plate 48; for if the two front tubes L and U are arranged so that their axes intersect vertically above the axle of the front wheel, the stresses are only pure tension and compression, so long as the force acting through the front axle is purely vertical. It is evident that this is not the case when the front wheel meets a brick or other obstacle which represents a force acting obliquely, as at O; whilst when the wheel drops on the other side of the obstacle, there is a shock which is vertical, as indicated at V. It is thus impossible to avoid bending; and the best compromise is obtained by making the axes of the two tubes meet some distance behind the perpendicular through the front axle, as shown in Fig. 1. This consideration is sufficient to justify the present shape of frame with short head H and horizontal top-tube U. Any considerable obstacle surmounted by the front wheel causes two distinct shocks, the first oblique and the second vertical; and these shocks will in general tend to bend the front tubes first in one direction and then in the other. The bending moments are greatest close to the head, just where the tubes have been weakened by brazing; it is therefore necessary to provide some local strengthening. This the author gives by shrinking a reinforcement about 5 inches long upon the outside of the tube ends, as shown full size in Fig. 6, Plate 50; the tubes are brazed together at the ends, tapered in a lathe, and the whole then brazed into the lug, as shown in Fig. 1. By this means the part weakened by the brazing is kept within the reinforcement, and breakage is practically impossible.

Large Tubes.—Although there is an evident advantage in increasing the diameter of tubes subjected to bending and tension, yet, as the thickness must be reduced in order to retain the same weight, a limiting ratio of diameter to thickness is soon reached, which cannot be exceeded without danger of the tube failing through buckling induced by some small local stress due to dents, etc. This ratio is much smaller when the tubes are curved, as in handle-bars, which if made of too thin metal will fail at the bend, and not at the junction with the stem where they ought to fail first if their strength is calculated from the bending moment only. In multicycles, where heavier tubes are necessary, the diameters may be considerably increased, with great advantage to the general strength and rigidity. For tandem and triplet cycles the author makes tubes 25 per cent. larger in diameter than for single machines, which gives about 50 per cent. more rigidity for the same weight.

Aluminium Frames.—The advantages of aluminium and its alloys, as compared with steel, have been so often urged that a few facts may be interesting. The best aluminium alloys have about 16 per cent. less strength and rigidity when drawn into tube than a steel tube of the same weight and outside diameter; but owing to its much greater thickness the aluminium tube can be made of larger diameter without danger of buckling. For handle-bars aluminium has greater advantages; and if it could be readily plated it would be really valuable for this purpose. The difficulty of jointing is much against it in most cases. For the comparison of strength and rigidity the tubes tested were both 1 inch outside diameter and practically of the same weight per foot; the steel tube was 20 gauge or 0·036 inch thick, and the aluminium alloy 12 gauge or 0·110 inch thick. The superiority of the steel tube was due to its greater mean diameter; making allowance for this, the strengths and stiffnesses of the two materials are nearly equal. The maximum stress in the steel tube was 52 tons per square inch, and in the aluminium alloy 18·7 tons per square inch. The effect of a brazing heat was to reduce the strength of the steel by 45 per cent., thus bringing down its maximum stress to 28·6 tons per square inch; the stiffness was unaffected.

Testing of Tubes.—In testing tubes it is necessary to take special precautions in order to avoid buckling by local stress. For example, if the tube is supported at the ends and loaded at the centre, it should be of considerable length, say 3 feet for 1 inch diameter; and the load should be suspended by a broad leather strap, so as to distribute the pressure over a large surface. Through the neglect of these precautions the results of many published tests have been rendered entirely misleading. The advantages so often claimed for "webbed" tubes are apparent only when the tube is tested in short lengths and loaded in the centre; under these conditions a plain tube is crushed in at the point where the load is applied, which is also the point of maximum compression stress due to the bending; it therefore fails prematurely from a local stress, which has no counterpart in the working stresses of a cycle. When tested with proper precautions, webbed tubes are both weaker and less rigid, weight for weight, than plain tubes: a result which accords with theory. The same may be said of various other sections. It is in many cases better to test by brazing a solid plug into one end of the tube, and having clamped this end, to load the other end; in this way all unfair stress is avoided. Corrugated tubes have the advantage of resisting local stress better than plain tubes; but they are less rigid, weight for weight, and present difficulties in jointing, as seen in Figs. 7 and 8, Plate 50. Nickel steel is as rigid as carbon steel, and has the advantage of a higher elastic limit; it is therefore well suited for the two front tubes of a cycle, which are the most subject to vibration. In other parts, where the elastic limit is not so nearly approached, it has no advantage over ordinary steel. It is a mistake to suppose that the mildest steel is the safest under vibration; owing to its low elastic limit it is more liable to break off short from vibration than harder steel containing up to 0·8 per cent. of carbon.

Means of securing Rigidity.—In considering the design of a safety bicycle frame, too little attention is generally paid to what may be called the driving stresses: that is, those set up by the pressure of the foot upon the pedal, which causes lateral distortion of the frame. There are two distinct cases to be considered: first, when the pressure of the foot is balanced by a pull at the handle on the same side; and second, when there is no pull at the handle.

In the first case, when the pressure of the foot is balanced by a pull at the handle on the same side, the distortion is confined mainly to the front part of the frame, Plate 48, consisting of the head tube H, the upper and lower front tubes U and L, and the seat-socket tube P. Each member of this quadrilateral is subjected to both torsion and bending. If any one of these members is so strengthened that its bending and twisting are diminished, then the strength of the adjacent members is also increased, so that much greater forces are required to produce a given distortion. Now the head tube being short compared with the other members, an increase in its thickness is accompanied by an increase in the stiffness of the frame out of all proportion to the increase of weight. This stiffness is also increased up to a certain point by shortening the head tube. The long heads in vogue a few years ago rendered the frame more springy; while the present pattern of frame, with horizontal top-tube U and comparatively short head H, is much better in this respect. The torsion of the seat-socket tube P is greatly diminished if the rear part of the frame is rigidly connected, instead of being merely bolted together. When the torsion of the head tube H and seat-socket tube P is thus minimised, rigidity is secured by providing top and bottom front tubes U and L of suitable diameter and thickness.

In the second case, when the pressure of the foot is not balanced by a pull on the handle, the distortion is not confined to the front part of the frame, but every member is twisted and bent simultaneously. The rigidity thus depends mainly on the joints throughout the frame. In Fig. 2, Plate 49, is shown the nature of the distortion observed in a machine wanting in rigidity. Here it will be seen that the wheels and the frame are no longer in the same plane; the wheel inclines to one side of the vertical, and the frame to the other, and the direction of the inclination alters at each stroke of the foot. The stresses thus set up are much the same as if the wheels were fixed, and the frame twisted by means of the seat pillar P. If the joints are made merely by flattening the ends of the tubes and then bolting up, as shown full size in Figs. 9 and 10, Plate 51, the frame is liable to be rickety; because under bending and twisting stresses such joints will give more than the whole length of the tube. This source of weakness is avoided in the author's practice by brazing the back forks F and chain stays S together, without any flattening or weakening of section, and by reinforcing the joint with a wrapping of sheet steel, as shown in Figs. 11 and 12. To the junction of the seat-socket tube the back forks are also brazed;

and the solid end-piece, after brazing in, as shown in Figs. 13 and 14, is recessed to take the seat-pillar bolt. This connection is so rigid as to permit of dispensing with the usual bridge above the back wheel. In the same way the ends of the front fork are stiffened so as to increase the lateral rigidity greatly, as compared with the usual make of flattened-tube fork-end. In the fork crown the weakest feature of the ordinary double-plate pattern is the smallness of the brazing surface, as shown half size in Fig. 3, Plate 49, which sometimes results in the tearing apart of the joint. This is remedied by fitting the fork blades into a practically continuous socket joining the crown plates, as shown in Fig. 4: thereby so greatly increasing the brazing surface as to reduce the maximum stress on the solder, and to eliminate all chance of breakage.

Chain Stays.—The chain stays are perhaps the most important part of the frame of a cycle; they are certainly the part about which the greatest difference of opinion exists. Before the extreme importance was realised of a narrow tread for constituting a straight-running machine, round chain-stays of 7–8ths inch diameter were often used, which gave ample stiffness; but now that there is a premium on every eighth of an inch under 5 inches clear width between the pedals, it is necessary to reduce this diameter to about 5–8ths inch. Now a tube of round section 5–8ths inch diameter is only about half as stiff as one 7–8ths inch diameter of the same weight, and has only about 70 per cent. of the strength. It therefore becomes necessary to use a section giving greater rigidity and strength than the ordinary round tube. The choice lies between oval, rectangular, and D sections. The last of these has been chosen by the author as the most suitable, in consideration of the nature of the stresses to be met. The weight of the rider puts the chain stays in tension; but this tension is small compared with that produced when the foot is exerting its maximum pressure on the pedal. The nature of the deformation produced by the chain tension may be investigated by tightening up the chain, and then squeezing its upper and lower spans together. It will be seen that both of the chain stays are thereby bent towards the chain side, because, being connected by the back axle, one cannot move without the other; and the final result is a bending in four places, two on each side, as shown in Fig. 15, Plate 52, namely close to the bridge and close to the back axle. The chain stays designed by the author are shaped with a slight bend in the middle, as shown in Fig. 16, so as to clear the crank end. This construction has been criticised as causing a bending moment at that point, tending to buckle inwards the stay on the chain side; but experiment shows that the total bending moment is not a maximum at that point, and that consequently the slight inward bend does no harm. On the other hand a sharp bend near the bridge is a source of weakness, which is best guarded against by using a steel casting at this point, instead of merely bending the tube. The bending moment, which is due to the back axle not being exactly in line with the back forks in some portions of the "chain adjustment," amounts in extreme cases to about 70 inch-lbs., which means only a small stress on the D tubes that are used. The stress moreover is perfectly symmetrical, and causes no lateral distortion of the frame. The advantage claimed for the radial or swinging adjustment, Fig. 17, Plate 53—namely that the axle A is always in the centre line of the back forks F—is thus of small account, and is far more than counterbalanced by the want of lateral stiffness in that adjustment. By the "chain adjustment" is meant the path of the back axle A along the slot provided in the end of the stay S for the purpose of adjusting the tension of the chain, as shown full size in Fig. 17: when the back forks F are bolted to the axle A, as in the radial adjustment, the weight of the rider is taken direct by the axle; but when the frame is brazed together at this point, as in Fig. 18, the axle moves away from the point where the centre lines intersect.

D *Tubes.*—On the subject of D tubes for chain stays there exists some amount of misapprehension. They were introduced by the author partly because the flat inner side is convenient for the nuts N on the back axle to be locked against, Fig. 21, Plate 54; and partly because, for the same width and weight, they are more rigid than either round or oval tubes. It must be borne in mind that, in order to attain the requisite rigidity, it is necessary in general to increase the section of chain stays beyond what is required for mere strength; it is therefore the rigidity of the different sections that has to be compared, and not their strength. It has been argued by a recent writer on cycle construction that weight for weight a tube of semicircular section is only 1 per cent. stronger than a tube of circular section, if both are of infinitesimal thickness. Now the **D** tubes employed by the author are not of semicircular section, and they are at least 20 gauge or 0·036 inch thick. A semicircular tube is about 23 per cent. stiffer than a circular tube, weight for weight, if both are of infinitesimal thickness; and when the thickness becomes finite, the advantage is still greater. A 5–8ths inch semicircular tube of 20 gauge or 0·036 inch thickness is about 32 per cent. stiffer than a 5–8ths inch circular tube of the same weight, since the thickness of the latter must be about 17 gauge or 0·054 inch, and its mean diameter is therefore less. The section used by the author however is not semicircular, but much more resembles the shape of the letter from which it takes its name, as shown full size in Fig. 22, Plate 55. Theoretically a rectangular section is the best possible; but its appearance on a cycle is so hideous as to be out of the question. If for equal weight the relative stiffness of a tube of circular section, 5–8ths inch diameter and about 17 gauge thickness, be represented by 100, then the results of tests of oval and **D** and rectangular sections, all three rolled from a round tube of 15–16ths inch diameter, will compare as follows:—

Round tube,	0·65 diameter × 0·054 thickness, relative stiffness					100
Oval	,, 0·65 wide	× 1·125 deep	× 0·036 thick,	,,	,,	119
D	,, 0·65	,, 1·070	,, 0·036	,,	,, ,,	136½
Rectangular	0·65	,, 0·825	,, 0·036	,,	,, ,,	146½

It will thus be seen that the **D** section now adopted is only about 7 per cent. less stiff than the rectangular, which is the best that can be rolled out of a round tube of the same diameter and to the same width.

Various webbed sections have from time to time been proposed, and advantages have been claimed for them on the strength of tests which mainly show resistance to local crushing in one particular direction, and give no indication whatever of the value of the section when made up into a cycle. Tests made on webbed D tube, by brazing a plug into one end and loading the other, show that it is 6 per cent. less strong and 15 per cent. less stiff than plain D tube of the same weight and external size. It is important to realise that the material of a tube should be kept as far away from the neutral axis as possible. This applies to various other sections, such as those shown in Figs. 23, 24, and 25, Plate 55.

Multicycles. — The necessity for lateral rigidity is even more apparent in multicycles than in single machines. It is found that any want of unison in the efforts of the riders has a disconcerting effect, which greatly detracts from the pace and from the power of going up hills. It is only by the employment of tubes of larger diameter that the increased distorting stresses can be properly met. The form of frame now generally adopted, shown in Fig. 19, Plate 54, was first used by the author in 1895, and has for its principal feature a horizontal tube I running from the bottom of the head H, parallel with the top tube U which starts from the top of the head; the lower line of tube I is braced by means of light diagonals to a single bottom-tube B of 1¾ inch diameter. This form of frame, whilst not superior in strength or rigidity to that having diagonals running from the top tube to the bottom without an intermediate tube, as shown in Fig. 20, possesses a great commercial advantage in the fact that frames can be built of different heights without altering the angles of the lugs, simply by raising the top tube U. It is advisable to unite the rear end of the intermediate tube I to the back forks by a short fork, as shown at J in Fig. 19, which increases the lateral rigidity. There seems to be a general tendency to duplicate the back fork F in multicycles; but greater rigidity can be secured by means of a single fork of large section, provided that it is properly connected to the top of the rear seat-pillar lug L, as shown in Fig. 19. In the same way a single tube B of 1¾ inch diameter connecting the various crank-brackets gives greater rigidity than the more usual arrangement of two 1-inch tubes, placed either side by side or one above the other.

Back Axle.—The method devised by the author of fixing the back axle by nuts N locking against the inner or flat side of the **D**-section chain-stays, as shown full size in Fig. 21, Plate 54, gives a rather wider spread to the back forks than is usual, which is an advantage in improving the bracing between the axle and the seat-pillar lug.

Chains.—The great advantage of a roller chain, shown full size in Figs. 26 and 27, Plate 55, when exposed to mud or dust, led the author to consider why the block chain, Figs. 28 and 29, was so generally admitted to be the faster of the two; and the conclusion he came to was that it is a question of smoothness of running. The roller-chain links were at least 1 inch long from centre to centre of eyes, whilst those of the block chain were alternately 0·4 and 0·6 inch. By shortening the links therefore to half an inch, he concluded that the roller chain would run more smoothly and consequently be faster than the block chain. It was found indeed that roller chains of 5-8ths inch pitch were already contemplated by the chain-makers; but as this length is slightly in excess of the longer of the block-chain links, there is no advantage in smoothness or speed. It was questioned whether the chain and wheel of half-inch pitch, shown half full size in Fig. 5, Plate 49, could be made a success in practice; but experience has fully justified the expectations on this point. The smoothness of running with gearing of this pitch is remarkable; whilst its excellent behaviour when covered with mud or dust renders a casing almost superfluous.

Gear and Crank Length.—The question of gear is so closely connected with that of crank length that they cannot properly be considered separately. For it is evident that a gear of 60 inches does not represent the same conditions with a 6-inch crank as when one of 7 inches is used; and similarly it would not be reasonable to expect that a leg 36 inches long will be suited by a length of crank which suits a leg 32 inches long. The length of crank must be decided by the rider's natural length of stride, and the ratio of multiplication of gear to length of crank must depend upon his muscular development: both of which data may be approximately ascertained by measurement. The gear is then the product of the two factors so determined. The maximum ratio of multiplication for road riding is about twelve times, and the minimum about nine times. The maximum length of crank may be taken as about 7½ inches, and the minimum 6 inches. Hence the gear may vary from 90 inches down to 54 inches.

Discussion.

Mr. **OSMOND** exhibited an extensive collection of specimens of the component parts of cycles in an unfinished state, illustrating the successive stages through which they had to pass and the nature of the work done upon them in each stage. Also various examples of finished work, and a completed bicycle of the most recent make.

Mr. T. **BUDWORTH SHARP** thought the construction of the frame of bicycles, like that of the locomotive, was now pretty well settled for some time to come. The great difficulty to be dealt with however was that of brazing, which, owing to the present practice of using a tube of uniform thickness throughout, weakened the frame at least as much as had been stated in the paper (page 287), namely nearly half. There were two ways of getting over that difficulty. One was to make a tube with thickened ends where the brazing took place. As an old tube-maker he believed there was no difficulty in making such tubes. If a tube were made 17 gauge or 0·054 inch thickness for the short length where the brazing took place, and the rest of the tube were 22 gauge or 0·028 inch thickness or even thinner, it would be much stronger than the present tube, and considerably lighter. The other way would be by using a mechanical fixing, and doing away with brazing altogether; because, even with a good method of brazing, a careless workman might get the metal over-heated, and it then came back practically to cast

(Mr. T. Budworth Sharp.)

metal. If brazing could be avoided and a mechanical joint be substituted, the latter he considered would be practically perfect: though he admitted that no mechanical joint he knew of was as firm as a good brazed joint. The nearest approach he had yet seen to a sound brazed joint was made by placing, inside the tube which had to go inside the socket, either a light aluminium plug or else a hollow internal liner, grooved round outside by a beading tool like a tube-cutter; then by another tool, like the converse of a Dudgeon roller tube-expander, both the external socket and the tube in between were pressed right into the grooves of the internal liner. In that way the mechanical hardness made in the drawing of the metal was not lost by the heat of brazing. If the loss of the mechanical hardness could be avoided, the frame might of course be still further lightened. It could also be lightened by the use of tubes with their ends thickened to such an extent that the extra local thickness more than made up for the weakness necessarily caused by the brazing. Of the two alternative methods he preferred the use of the extra thickness at the place where the brazing was done. Frames so made were at once lighter and stronger.

Mr. OSMOND doubted whether, if a mechanical joint could be devised, it would give the same rigidity and security as a brazed joint, even though the heat of the brazing did somewhat deteriorate the hardness of the metal. The thickened ends suggested for the tubes were the very thing he had been waiting for, but they had not yet appeared. When he could get such thickened ends, he should be glad to use them. Meanwhile he had recourse to the reinforcement described in the paper.

The PRESIDENT proposed a vote of thanks to Mr. Osmond for his paper, and for the interesting series of specimens he had exhibited in illustration of the construction of cycles.

THE CITY OF BIRMINGHAM CORPORATION WATER WORKS.

By Mr. HENRY DAVEY, Member of Council.

Historical.—For supplying with Water the town and neighbourhood of Birmingham, a company was incorporated in 1826, and in the same year obtained their first act of parliament, fixing their capital at £120,000, with power to borrow £30,000 more. The source of supply was the river Tame only; and a storage reservoir capable of containing 30 million gallons was constructed at Aston, into which the water from the Tame was turned on 17th August 1831. The further initial works were two pumping engines at Aston, still in use; and a storage reservoir in Monument Lane, Edgbaston, having a capacity of 4¼ million gallons.

In 1838 the town of Birmingham was incorporated; and the new Corporation appear to have entertained almost from the commencement the idea of acquiring the Water Works undertaking. The Birmingham Improvement Act passed in 1851 included a clause which empowered them to supply water to the borough, and to purchase the existing works at a price to be fixed by arbitration or by a jury. In 1853, their capital being exhausted, the company determined to apply for additional powers; and in March 1854 the corporation gave notice under their act of 1851 to purchase the undertaking. The company obtained their act on 2nd June 1854, whereby their authorised capital was raised to £240,000, and their borrowing powers to £60,000. The act recited the notice from the corporation of their intention to purchase; and enacted that for three years thereafter new works proposed to be executed by the company should be subject to the borough surveyor's approval. The contingency of the corporation purchasing the undertaking within two years from the date of their notice given in 1854 was also provided for.

In consequence of the poisoning of the Tame in September 1854, the supply of water to the town was entirely cut off for some days. The necessity for a further source of supply being thus brought home to the company, they obtained a further act in 1855, increasing their capital to £420,000, and their borrowing powers to £105,000. The works were immediately extended by the construction of additional reservoirs at Witton, impounding the water of the Perry stream and of the Hawthorn brook or Witton stream; and from time to time the works were further extended. After an unsuccessful application in 1865, a further act was obtained on 11th June 1866, whereby the area of supply was considerably extended, and the capital increased to £756,000, and the borrowing powers to £189,000.

Preliminary borings had already been made at Aston, with a view to the construction of a deep well. These mark a new start in the water supply of the town; and from this date the company turned their attention to obtaining supplies from deep wells, which after the first well at Aston were sunk successively at Kings Vale, Perry, and Witton, the locality of the last being now called Short Heath. By their last act, obtained on 14th July 1870, their capital was not altered, but the area of supply was extended, and power was given for the construction of new works, which included a well at Selly Oak, a storage reservoir at Erdington, and the present extensive works at Whitacre and Shustoke for impounding the water of the rivers Blythe and Bourne. It was provided that the water from the rivers should be carefully filtered; and power was given to the corporation to appoint an inspector for testing the quality of the water. In 1872 a small reservoir at Whitacre was completed, and the water of the Blythe was brought into use; part of the land was purchased for the large reservoir at Whitacre, and also for the proposed well at Selly Oak; and in 1874 the land for the storage reservoir at Erdington was purchased. This practically completes the history of the undertaking as the property of the company, whose capital at the close of 1875 stood as follows :—

	Capital.	Borrowing Powers.
Authorised by act of 1826 . . .	120,000	30,000
„ „ 1854 . . .	120,000	30,000
„ „ 1855 . . .	180,000	45,000
„ „ 1866 . . .	336,000	84,000
Total at end of 1875	£756,000	£189,000
Amounts actually raised . . .	£672,000	£189,000

In 1874 application was made to parliament by the corporation for the transfer of the undertaking by agreement or for its compulsory purchase; the advisability of its acquisition was urged as a matter of public policy rather than of finance. An act empowering the purchase was obtained on 2nd August 1875, and the transfer was effected on 1st January 1876 in consideration of £54,491 in perpetual annuities, made up as follows:—

£	
33,600	—being the maximum dividend of 8 per cent. on the £420,000 capital authorised under the act of 1855.
17,640	—being the maximum dividend of 7 per cent. on the £252,000 capital subsequently called up.
2,376	—in respect of possible profit on the remaining £84,000 capital not called up.
875	—as compensation for back dividends unpaid.
£54,491	—total in perpetual annuities.

The debt of £189,000 incurred under the borrowing powers was taken over by the corporation. Assuming the annuities to be capitalised at twenty-five years' purchase, the £54,491 a year was equal to £1,362,275, and comprised a premium or goodwill of £690,275, that is, the difference between the £672,000 capital of the company and the capitalised value £1,362,275 of the annuities. The capital at the time of the transfer was thus £1,362,275 plus the debt of £189,000, making £1,551,275 total.

The management of the undertaking then devolved upon the corporation, who carried out certain works initiated by the company, and at once took steps for compelling the owners of properties which were without satisfactory water supplies to lay on supplies from the water works mains. The revenue during 1875, the last year before the transfer, was £87,350; and under the corporation it advanced to £127,504 by 1882, notwithstanding that in 1881 reductions of water rents had been made to the extent of £5,000 per annum. The act of 1875 empowered the raising of £250,000 additional capital, of which £100,000 was subject to the approval of the Local Government Board. The extensions of mains and the construction of other works quickly exhausted these powers; and as the increasing demand for water required the construction of still further works, it was deemed expedient to renew the lapsed powers previously obtained for the construction of the works at Shustoke for impounding the water of the river Bourne. Accordingly in 1879 an act was obtained renewing these powers, and authorising the borrowing of £300,000 additional, thereby bringing the authorised capital up to £2,101,275.

Welsh Supply.—The area of water supply at the present time comprises a population of 725,000, of which it is estimated that about 688,500 are actually supplied. The number of houses supplied on 31st March 1897 was 137,703, in addition to 11,522 miscellaneous unmeasured supplies for purposes other than domestic. There were also at that date 2,850 supplies by meter for trade purposes. From 8,300,000 gallons in 1876 the daily demand for water continued to increase, so that in the year ended 31st March 1891 it had risen to nearly double that amount, or 16,500,000 gallons. The increasing demand led to the apprehension that in the near future the sources of supply would become insufficient; and after full enquiry an act was obtained on 27th June 1892, whereby the corporation were empowered to obtain a supply of water from the rivers Elan and Claerwen in Radnorshire. The capital authorised is £6,600,000. The Welsh supply scheme was prepared and carried through parliament by Mr. James Mansergh, who is now carrying out the first portion of the work, by means of which 27 million gallons per day may be brought into Birmingham by gravitation at an elevation of 603 feet above ordnance datum; the ultimate quantity available will be 67½ million gallons per day, and the total length of the aqueduct is about 73 miles. It will be several years before the works can be completed, and the Radnorshire water be distributed in Birmingham. The model exhibited of the watershed, which has been kindly lent by the Water Committee of the Corporation, gives a general idea of the new works, which will stand in the foremost rank among the great works of water supply for large communities.

Interim Resources.—In the meantime it is necessary to meet the growing demand for water, and to maintain the present works in an efficient state. In view of the large expenditure on the new supply, it is also important that the capital expenditure on the old works should not be more than absolutely necessary. At the present time the water supply for Birmingham is derived partly from streams and partly from wells. The streams are the rivers Bourne and Blythe at Whitacre, Plants brook, and the Perry stream. The average quantity taken from them annually is equal to about 10½ million gallons per day, and the average quantity taken from the wells is about 6 million gallons per day, the average daily consumption for the last year being about 16½ million gallons, with a maximum of 21 millions. The whole of the water taken from the streams, and some of that from the wells, is passed through filter beds, where it is efficiently filtered before being mixed with the rest of the well water, and pumped into the service reservoirs for distribution. The domestic and trade consumption of water has greatly increased with the increase of population; but the quantity distributed has been kept down by reducing waste and economising in various ways. The past year has been an exceptionally favourable one with its mild winter; a severe winter increases the average consumption by waste from burst mains, running taps, &c. In Plate 59 are shown the weekly fluctuations in the pumping returns during the year ending 1st April 1897. The height of the successive steps in the diagram is accounted for by the varying storage in the service reservoirs; a fair curve through the mean of the steps would indicate the variation in the actual consumption.

Service Reservoirs.—These are so situated as to divide the water area into three zones of distribution, which are indicated in Plates 56 to 58:—first, the low-level zone, supplied under pressure from the Erdington reservoir, in which the top water is 469 feet above ordnance datum; second, the mid-level zone, supplied under pressure from the Monument Lane reservoir, Edgbaston, in which the top water is 532 feet; and third, the high-level zone, supplied under pressure from the Hagley Road reservoir, Edgbaston, in which the top water is 601 feet above ordnance datum. A portion of the high-level zone being at about this same elevation, and therefore too high to be supplied through the reservoir, is supplied through a stand-pipe, the top of which is 650 feet above ordnance datum.

Pumping Stations.—The general plan of pumping, by which the three service reservoirs and the stand-pipe are kept well supplied, is shown in the diagram, Plate 58, which is a combined longitudinal section following the principal lines of mains; and the localities of the various stations are shown in the map, Plates 56 and 57. A complete summary of all the pumping engines both at the pumping stations and at the wells is given in Table 1, pages 304–5.

Whitacre.—Beginning with the Whitacre pumping station at the lower end, the Shustoke reservoir at half a mile distance has a capacity of 442 million gallons, and receives its supply from the river Bourne. A smaller reservoir holding 32 million gallons is supplied from the river Blythe. The Shustoke reservoir is at a sufficient elevation to deliver its water direct to the filter beds; but steam pumps are employed to pump up to them from the Blythe reservoir, which is at a lower level. The filter beds have a collective area of 183,504 square feet, and are large enough to allow of as much as 10 million gallons per day being pumped from this station. There are two compound pumping engines, each having cylinders 33 and 60 inches diameter by 10 feet stroke, and each working a pair of 26-inch plunger pumps of the same stroke; also two Cornish engines, each having a cylinder 72 inches diameter by

11 feet stroke, and a 24-inch plunger pump of 10 feet stroke with a filter pump 30 inches diameter and 7 feet stroke. The engines are supplied with steam from a range of water-tube boilers, some of which are worked at 70 lbs. pressure for the compound engines, and the rest at 30 lbs. pressure for the Cornish engines. The pumping main from Whitacre is 36 inches diameter, and extends viâ Plants Brook to the Erdington reservoir, a distance of about eight miles.

Steam Pumps.—The steam pumps for lifting the water to the filter beds from the Blythe reservoir were originally worked non-condensing, with low-pressure steam from the boilers supplying the Cornish engines. They are of the duplex type, carrying full steam throughout the stroke without expansion. They originally exhausted into the atmosphere, and consumed a large quantity of steam, almost as much as would work one of the large Cornish engines. Finding that the cylinder capacity of the pumps was sufficient for enabling them to be worked with the difference in pressure between the high and the low-pressure boilers, the author made the following alteration for reducing their consumption of steam. From the high-pressure steam main, Plate 60, a new supply pipe was led direct to the steam pumps, whilst the exhaust was conveyed by another pipe into the low-pressure steam main of the Cornish engines. The economy of fuel resulting from this alteration has been great, while in addition a distinct advantage has been secured from the pumps now working against a back-pressure, instead of exhausting freely into the atmosphere; they work much quieter, and a greater speed is obtained with less wear and tear. The principle of this simple alteration had already been adopted by the author in another instance nearly twenty years ago, and may have been resorted to by other engineers also.

Plants Brook.—Here there is a storage reservoir of 33 million gallons capacity, with filter beds of 99,991 square feet area, and two pumping engines; one is a Cornish engine, having cylinder 60 inches diameter by 9 feet stroke, with a 26-inch plunger pump; the other is a compound engine, having cylinders 28 and 48 inches diameter

TABLE 1 (*continued on opposite page*).

Pumping Engines
at Pumping Stations and at Wells.

PUMPING STATIONS.	Description of Engine.
Aston	Atlas 1828 Cornish Hercules 1830 Cornish Neptune 1852 Cornish Jupiter 1853 Cornish Eagle 1867 Rotative Hawk 1867 Rotative Castor 1881 Compound Pollux 1881 Compound
Whitacre	No. 1 Cornish † {and a filter pump 30 inches No. 2 Cornish † diameter and 7 feet stroke} No. 3 Compound No. 4 Compound
Plants Brook . . .	No. 1 Cornish No. 2 Compound
Edgbaston . . .	No. 1 Cornish No. 2 Compound
WELLS.	
Aston	No. 1 Cornish No. 2 Cornish
Perry	Rotative Beam with Gearing
Short Heath . . .	Cornish Bull
Selly Oak . . .	Cornish
Longbridge . . .	Horizontal Compound
Kings Vale . . .	Rotative Beam with Gearing

(*concluded from opposite page*) TABLE 1.

Pumping Engines
at Pumping Stations and at Wells.

Steam Cylinder.		Pump.			
Diameter.	Stroke.	Diameter.	Stroke.	Strokes per min.	Height of Lift.
Inches.	Feet.	Inches.	Feet.	No.	Feet.
60¼	8	21	8	10	250
60¼	8	21	8	10	250
72	10	23	10	10	250
72	10	23	10	10	250
48	8	19½ & 27¾	4	10	250
48	8	19½ & 27¾	4	10	250
16 & 32	5	20	* 5	14	80
16 & 32	5	20	* 5	14	80
72	11	24 †	10	12	270
72	11	24 †	10	12	270
33 & 60	10	26	*10	10	260
33 & 60	10	26	*10	10	260
60	9	26	8	10	210
28 & 48	8	26	* 4⅔	10	210
36	9	21	8	12	130
16 & 32	5	20	* 5	15	130
			* Double-acting pumps.		
48	10	30	10	3	110
60	9	20	* 7	5	350
56	5	20	* 9	5½	90
60	9	30	9	8	90
60	11	17	* 7	4	330
27 & 48	5	18	* 5	3⅓	285
33	4⅙	18	* 5	7	110

by 8 feet stroke, working two plunger pumps of 26 inches diameter by 4 ft. 8 ins. stroke. Both engines are supplied with steam from the same range of water-tube boilers, at a working pressure of 45 lbs. per square inch.

Testing of Engine Slack.—This station is used for testing the quality of the engine slack supplied to the various pumping stations. Each test is made with 500 cwts. of slack, the feed-water being measured into the boilers by a Kennedy meter; the number of strokes made by the engine is recorded by a counter, the head of water pumped against is noted, and care is taken to preserve the conditions as uniform as possible during all the tests. This mode of ascertaining the evaporative efficiency of the slack enables that quality to be selected which gives the most economical results. The general prices of engine slack do not vary in proportion to its evaporative efficiency; and without some means of testing from time to time, the slack may be bought at much too high a cost.

The water pumped at Plants Brook station is delivered 3½ miles to the Erdington reservoir, from which, together with that pumped at Whitacre, it is conveyed to Aston, supplying the low-level zone by direct pressure from Erdington. The quantity being much greater than that required in the low-level zone, the surplus is pumped at Aston into the mid-level zone under pressure from the Monument Lane reservoir. This surplus is pumped by two compound pumping engines, each having cylinders 16 and 32 inches diameter by 5 feet stroke, and each working a pair of plunger pumps 20 inches diameter by 5 feet stroke. The suction of the pumps draws from the Erdington main, whilst the delivery is into one of the mains leading to Monument Lane; in this way the pressure on the suction side of the pumps is utilized, and the work done by the engines is only the difference in pressure between the mid-level and low-level zones.

Aston.—The station at Aston is the largest and most important of the pumping stations, and the bulk of the water derived from various sources is brought here to be pumped up into the Monument Lane reservoir, Edgbaston, whence part of it is again pumped to supply the high-level zone.

Wells.—On the Aston side of Edgbaston there are five wells, yielding daily the following quantities of water:—Aston No. 1 well 660,400 gallons, No. 2 well 1,288,100; Perry well 1,100,000; Kings Vale well 363,000; and Short Heath well 1,600,000 gallons. On the other side of Edgbaston there are two other wells, one at Longbridge yielding last year 425,000 gallons per day, and the other at Selly Oak yielding last year 513,000 gallons. The water from the wells on the Aston side is pumped to distribution by the engines at Aston; whilst the Longbridge and Selly Oak wells are provided with engines which partly supply the high-level zone in connection with the Hagley Road stand-pipe.

Aston Engines.—The Aston pumping station was established by the water company incorporated in 1826. There were erected as far back as 1828 and 1830 two pumping engines still existing, named Atlas and Hercules, which have been kept at work ever since, excepting the necessary stoppages for repairs from time to time; they are now in first-class order, and are likely to last as long as they will be required. Their cylinders are constructed on the Cornish plan, and are 60¼ inches diameter by 8 feet stroke; but as the pumps are of the bucket kind, the engines cannot profitably be worked expansively. The other engines at Aston station are the following:—two Cornish engines erected in 1852 and 1853, each having a cylinder 72 inches diameter by 10 feet stroke, with a 23-inch plunger-pump of same stroke (Proceedings 1853, page 110); a pair of coupled fly-wheel engines erected in 1867, having cylinder 48 inches diameter by 8 feet stroke, with two bucket-and-plunger pumps, each 19½ and 27¾ inches diameter in the barrel; also the two compound engines previously mentioned (page 306), which were erected in 1881. All these eight engines, or as many of them as may be required from time to time, are employed to pump to the mid-level zone, and into the Monument Lane reservoir. The six single-cylinder engines are all working with low-pressure steam of about 20 lbs. per square inch, supplied from three sets of Cornish and Lancashire boilers; whilst the compound engines are supplied with steam at 70 lbs. per square inch from a separate range of water-tube boilers.

With a view to effect an economy in fuel consumption without the necessity of a large capital expenditure, and at the same time to provide additional pumping power for meeting the maximum demand on the station, the author has lately had recourse to the principle involved in the alteration already described of the duplex steam-pumps at the Whitacre station. A compound non-condensing direct-acting engine has been provided, having cylinders 26 and 37 inches diameter by 5 feet stroke, working a horizontal double-acting plunger-pump of 22 inches diameter. It is being placed on a simple foundation in an inexpensive building; and to provide it with steam, one of the old ranges of low-pressure Lancashire boilers which were almost worn out is being replaced by a range of high-pressure Lancashire boilers working at 130 lbs. per square inch. The two remaining sets of low-pressure boilers have been connected by a trunk steam-main, from which the three pairs of low-pressure engines take their steam supply, and into which the new compound engine will exhaust. The arrangement of steam supply is shown in the diagram, Plate 61. The high-pressure boilers are to be fed with water taken from the mains, and passed through a feed-water heater, in which the water will be heated with steam taken from the equilibrium pipe of the Cornish lift engines; in this way the water can be heated nearly to the boiling point with the waste steam of the engines, notwithstanding that they are condensing engines. It so happens that their equilibrium steam is at a pressure above that of the atmosphere, because but little expansion is here possible, owing to the fact that the engines work bucket pumps. This method of feed heating is shown in Fig. 6, Plate 62; and Fig. 7 represents the steam diagrams from the engines.

Edgbaston Station.—The engine power at this station, and also that at Longbridge and Selly Oak, is employed for the purpose of supplying the high-level zone under pressure from the Hagley Road reservoir and stand-pipe. The consumption of water for domestic supply varies so largely at different hours of the day that in pumping under the stand-pipe pressure, without any overflow, the speed of the engines would also have to be largely varied during the day, in order to meet the varying demand of the stand-pipe district. The Edgbaston engines are therefore made to supply the reservoir for the high-level zone by overflow through the stand-pipe; and the stand-pipe itself has to supply only the higher portion of the zone. By restricting this higher portion within proper limits, the full pressure is always maintained in the stand-pipe, although the engines are only just capable of pumping the mean supply of both districts; in other words, the maximum draught in the higher or stand-pipe district does not exceed the combined mean draught of this higher portion and of the rest of the high-level zone.

Dry Seasons.—As already mentioned, the total supply of 16½ million gallons per day is made up of about 10½ millions from streams, and 6 millions from wells. During a dry period of say 180 days, the water-sheds supplying the streams may be calculated to yield from 7 to 8 million gallons per day; which together with the total storage of about 500 million gallons would give a daily supply of a little over 16½ million gallons. The total average yield of the wells cannot be increased, and tends to diminish; and from experience gained it is evident that but little more water could be expected from underground sources. It will be seen that some of the wells yield but small quantities. During last summer 1896 the storage was so heavily drawn on that it was the cause of much anxiety. It has been necessary to adopt the strictest economy of water by the prevention of waste and by other means. In 1894 the average gross consumption per head per day was 25·92 gallons, and in 1896–7 it had been reduced to 23·70 gallons. In the same period the net consumption per head for domestic supply, fire, and waste, was reduced from 19·62 gallons to 15·11 gallons. In the year to 31 March 1897 the average consumption per head per day was as follows:—

Gross consumption	23·70 gallons
Consumption for measured trade supplies, and for railways, road watering, markets, etc.	4·39 gallons
Estimated consumption for unmeasured trade supplies, say	4·20 gallons
Net estimated consumption for domestic use, fire, and waste	15·11 gallons

In the diagram, Plate 59, is shown the variation in the water consumption throughout the year 1896–7; but far greater variation takes place in years of severe winter and dry summer. The total revenue of the water department for the year to 31 March 1897 was £202,059.

Cost of Pumping.—This varies greatly with the different stations. The small stations with small supplies are exceedingly expensive; but the large stations are working with fair economy. At Whitacre the total cost of pumping 1,000 gallons of water 100 feet high, including coal, salaries, wages, and stores, averages under one farthing.

Hydraulic Power Supply.—Being owners of both the gas and the water works, the corporation of Birmingham established some years ago a hydraulic power supply, which was placed under the management of the water department. The station is situated in Dalton Street, near the Old Square. The hydraulic power is produced by means of gas engines and pumps; the engines take gas from the gas mains, and the pumps take water from the water mains in the mid-level zone, and are therefore under pressure from the Monument Lane reservoir. There are three Otto-cycle gas-engines, two of 20 H.P. each, and one of 12 H.P.; each engine drives by means of belts and gearing a set of three-throw pumps. The pressure in the delivery mains is 750 lbs. per square inch. The supply is governed by means of two accumulators, each loaded to about 90 tons and one slightly heavier than the other; each accumulator has a ram 18 inches diameter by 20 feet stroke. The starting of each of the gas engines is effected by means of a three-cylinder hydraulic engine, taking its power from the hydraulic main. By means of a hand lever a small pulley on the shaft of the hydraulic engine is pressed against the rim of the gas-engine fly-wheel, and by the frictional contact the engine is turned round. The charges for hydraulic power are made on the following sliding scale:—

	£.	s.	d.
20,000 gallons per quarter	6	10	0
50,000 „ „	13	0	0
80,000 „ „	17	10	0
100,000 „ „	20	10	0
300,000 „ „	43	0	0

The average revenue per thousand gallons during the year ending 31 March 1897 was 65·4 pence. Already 3¾ miles of hydraulic mains have been laid, and the station is arranged for a large extension of machinery whenever found necessary.

In conclusion, attention may be drawn to the photographs exhibited of some of the pumping stations. The author desires to acknowledge his indebtedness to Mr. E. Antony Lees, the secretary of the water department, who has kindly got together for him the notes on the history of the undertaking.

Discussion.

Mr. DAVEY said there was one interesting point as to which he was sorry he was unable to give accurate figures, namely the fluctuation in the daily supply. The fluctuation in the weekly and yearly supply was clearly shown in the diagram, Plate 59, and might be taken as correct. In describing the use of the stand-pipe for the higher part of the high-level zone (page 309), he had mentioned that the high-level zone was divided into two portions, and that these were so proportioned that, by supplying the lower by the overflow from the stand-pipe, the maximum supply in the higher or stand-pipe district should always be kept up. From some experiments already made the daily supply had been found to vary much in the different districts. In the high-level district, which was chiefly residential, the variation was something like that represented

(Mr. Davey.)

by the following figures:—7 maximum, 4½ mean, and 2¼ minimum. This was a greater variation than in the manufacturing districts, because in the latter the manufacturers used water at night also.

Mr. MICHAEL LONGRIDGE said the arrangement for compounding the high and low-pressure engines (page 308) seemed to fit in well with present circumstances, inasmuch as it would probably be necessary to dispense with a great deal of the present pumping power within a short time. It was an arrangement which he had himself used in print and dye works, where in addition to power a good deal of steam was required for drying and boiling. In such cases the power might be obtained from non-condensing engines, and the steam discharged from these engines might go into a range of low-pressure steam-pipes which supplied drying tables and boiling machinery. The quantity of steam which the non-condensing engines discharged could be conveniently regulated by varying the pressure and the degree of expansion. If a large supply of steam was wanted for boiling and for manufacturing purposes, the expansion valve was opened out and the initial pressure lowered, whereby the discharge from the cylinder became much greater than when cutting off early and discharging the steam at low pressure.

There was only one question which he wished to ask, namely why water-tube boilers had been adopted for low pressures. There had always been a considerable difficulty he believed in working water-tube boilers with low pressure; and he should be glad to know whether any difficulty in this respect had been experienced here.

Mr. BRYAN DONKIN, Member of Council, enquired about the gas engines and pumps used in the hydraulic power station (page 310), as to the consumption of gas and its heating value, and also the quantity of water pumped; these data would enable the efficiency of the engines to be realized.

The arrangement for the testing of engine slack at Plants Brook station (page 306) seemed to be excellent. It would be interesting if the maximum and minimum amount of water evaporated per lb. of coal could be added, with the percentage of dirt and the calorific value of the coal, as well as the boiler efficiency and the particular kind of boiler used.

Professor W. **CAWTHORNE UNWIN** noticed that in testing the engine slack (page 306) a considerable quantity of slack was used, but there were no tests of its calorific value. In this respect there appeared to him to be a serious defect in the process employed. Apparently coals were being used of different composition and aggregation. Of the heat produced by coal it should be remembered that fully 30 per cent. went up the chimney. Whether therefore a test of two different coals gave either a good or a bad result would depend upon whether the same proportion of heat went up the chimney in each case. It appeared to him that no precaution had been taken for ascertaining the heat escaping with the different quantities of coal burnt. Without some measure of that kind the test would be deceptive. The experiment was interesting, and in the right direction; but it was not of much use to test coal in large quantities in an ordinary boiler, unless an effort was made to show how much heat was being thrown away. It was necessary to be sure that each quality of coal was being burnt under good conditions and with the air supply most suitable for it.

Mr. H. A. **PERTWEE** enquired how it was intended to work the compound non-condensing engine (page 308) in connection with the three pairs of low-pressure engines. Presumably the expansion valve of the compound engine would have to be adjusted to suit the pressure in the low-pressure trunk steam-main; and it appeared to him that, with a certain amount of work to be done by the compound engine and also by the Cornish engines, it was rather a peculiar plan to exhaust direct from the compound engine into the low-pressure steam-main, on account of thereby causing a variable back-pressure in the low-pressure cylinder of the compound engine. If the pressure in the exhaust pipe from the compound engine was made the same as that in the low-pressure steam-main by the adjustment of the expansion, as suggested by Mr. Longridge (page 312), it seemed to him that the compound engine would have to be limited in its work in order to be able to make such an adjustment.

Mr. DAVEY explained, in regard to the use of water-tube boilers for generating steam at low pressures, that these boilers had been erected some of them fifteen and others twenty years ago, and he was not aware of the reasons which had influenced their selection at the time. For any recent extensions he had not himself adopted water-tube boilers either for low or for high pressure, but used Lancashire boilers only. Those recently erected at Aston were indicated in the diagram, Plate 61. His experience was that the Lancashire boilers were much more economical than water-tube boilers, and certainly gave much less trouble. For low pressures he certainly should not put water-tube boilers, and he doubted whether he should do so even for high pressures, seeing that Lancashire boilers could now be made perfectly satisfactory for any pressure which it might be found useful to employ.

As to the gas engines in use at the hydraulic power station, the total quantity of water they had pumped into the hydraulic power system, and the consumption of gas, which was the ordinary lighting gas taken from the city mains, had been as follows during the past four years :—

Year ending 31 March	1894	1895	1896	1897
Water pumped for hydraulic power, million gallons	2,443	3,182	3,585	4,726
Gas consumed per thousand gallons pumped, cubic feet	555	439	386	308

The whole arrangement worked most satisfactorily. The station in Dalton Street was not far distant, so that any members desiring to see it at work could readily do so.

In reference to the testing of engine slack, he agreed with Professor Unwin that, if the object really was to find out the exact calorific efficiency of the coal, it would be necessary to make more complete observations than those which were at present being made; but the test used was eminently a practical one. The boilers were similar to those employed in all the other pumping stations, and the method of stoking was the same; and all that it was necessary to discover was what was the cheapest coal to buy under the circumstances in which it was used. For correct scientific results it would no doubt be desirable to go into the elaborate experiments to which Professor Unwin had alluded.

There was no idea of adjusting the expansion valve on the compound engine in order to bring the high-pressure steam from 130 lbs. per square inch in the high-pressure boilers down to 20 lbs. in the low-pressure boilers. There were three sets of stokers at work, whose duty was to keep up the pressures at 130 lbs. and at 20 lbs.; and they varied the stoking to suit these requirements. After the steam distribution had once been properly adjusted in the first instance to suit the constant work of pumping, there was no question of making any further adjustments; the whole distribution thenceforth took care of itself.

The President proposed a vote of thanks to Mr. Davey for his paper, which was passed.

HIGH-SPEED SELF-LUBRICATING STEAM-ENGINES.

BY MR. ALFRED MORCOM, OF BIRMINGHAM.

The subject of High-Speed Engines is one of such real importance and interest, that it may be useful and appropriate on the occasion of the present meeting to give some account of the part taken in their development by the writer's firm, Messrs. G. E. Belliss and Co., of this city.

Steam Cutters and Pinnaces.—In 1864 the firm commenced, with Mr. J. S. White of Cowes, to supply to our own and foreign governments steam cutters and pinnaces for use with warships. These small boats, which are now such a feature in all our harbours, were at that time unknown. The first boat was a steam life-cutter, built for the late Marquis of Hastings; and the primitive engine used in it is shown in Plate 63, having a single cylinder $5\frac{1}{4}$ inches diameter and 6 inches stroke. With all these small craft throughout, for naval and private purposes, the problem has been the same: namely to get the greatest power that can be developed out of a given weight of machinery, with a reasonable factor of safety. As far as the engines are concerned, exceeding care with the design and the materials, and quick revolutions, have alone rendered advances possible in this direction; but the limits have necessarily been soon reached, and in recent years the chief advances have been made in the boilers, with forced draught to assist the combustion. The shallow draught of these vessels requires a small diameter of propeller; and this, together with the necessity for minimum weight of machinery, has always required the speed of revolution to be kept high. In these small boats, which are carried on board the ships of war, the machinery varies in power from about

12 I.H.P. in the cutters to 200 I.H.P. in the vedette boats. The gradual progress made is illustrated by the fact that in the first vedette boat built a speed was obtained of 14 knots with 142 I.H.P. for a total weight of 5½ tons of machinery, including water in boilers, and in the last a speed of 17·88 knots with 206 I.H.P. for the same weight of 5½ tons.

Torpedo Boats.—A considerable number of sets of machinery have also been built for first-class torpedo-boats, and for torpedo-boat destroyers; and last year the machinery was completed for two of the latter vessels, the "Spitfire" and "Swordfish," built by Sir W. G. Armstrong, Whitworth and Co. The particulars of the machinery and of the trials are given in Tables 1 and 2, and the engines are shown in Plates 64 to 67. The general features of these engines by all makers are similar. The engine bearers are separate light steel castings, supported on the angle frames running fore and aft between the bulkheads. From these bearers the cylinders are carried by forged steel columns suitably braced. All the working parts are made as light as possible, as the momentum, due to the high piston-speed of 1,250 feet per minute on trial, is a considerable factor in the working of the machinery. A peculiar feature in these engines, which has considerably assisted in the excellent results obtained, is the arrangement of the cylinders, the low-pressure being divided into two equal cylinders with cranks opposite, and the high and intermediate being also arranged with cranks opposite. This permits the fitting of two links instead of four, reduces the fore and aft space considerably, leaves the ends clear for thrust and air-pump, and gives well-balanced pressures on the shaft bearings. This design was here adopted, because it has proved so effective and satisfactory in the two-crank compound engines, of which large numbers have been built by the writer's firm for supplying electric light and power. The absence of four sets of link motion and accompanying gear will be fully appreciated by everyone who has had charge of machinery, developing such large power in such small space, as is necessary in torpedo-boat destroyers. The engines are balanced by small weights on the crank cheeks, placed

TABLE 1.—*Full-power Trials of H.M.S. "Spitfire,"* 17 *Aug.* 1896.

Draught of water, forward 5 ft. 2 ins., aft 7 ft. 4¾ ins.
Speed of ship, mean for three hours 27·461 knots,
mean on measured mile 27·775 knots, maximum 28·571 knots.

			Three hours full-power.		Six runs on measured mile.	
Air pressure in stoke-holds		inches of water	3·09		2·76	
Steam pressure in boilers, per square inch above atm.		lbs.	195		198	
			Right	Left	Right	Left
Vacuum in condensers,		inches of mercury	24·3	23·6	24·5	24·0
Revolutions per minute		revs.	401·9	395·7	408·7	403·6
,, ,, ,, mean		revs.	398·8		406·2	
Steam pressure in reservoirs, per sq. inch above atm.	high	lbs.	187	187	185	186
	inter	lbs.	87	90	85	87
	low	lbs.	24	25	24	24
Mean pressure in cylinders, per square inch	high	lbs.	68·0	70·2	65·3	69·3
	inter	lbs.	30·7	33·3	30·4	32·7
	low forward	lbs.	20·2	20·6	20·2	19·8
	low aft	lbs.	19·8	18·8	19·2	19·3
Mean indicated horse-power	high	I.H.P.	686	697	668	700
	inter	I.H.P.	651	700	657	699
	low forward	I.H.P.	453	457	460	445
	low aft	I.H.P.	446	416	439	437
Total power of each set		I.H.P.	2236	2270	2224	2281
Joint power of both sets		I.H.P.	4506		4505	

TABLE 2.—*Full-power Trial of H.M.S. "Swordfish,"* 21 *Oct.* 1896.

Draught of water, forward 5 ft. 2½ ins., aft 7 ft. 5 ins.
Speed of ship, mean for three hours 27·117 knots.
Air pressure in stoke-holds 2·3 inches of water.
Steam pressure in boilers 203 lbs. per square inch above atm.

			Right	Left
Vacuum in condensers		inches of mercury	24·1	24·4
Revolutions per minute		revs.	399·2	398·2
,, ,, ,, mean		revs.	398·7	
Mean pressure in cylinders, per square inch	high	lbs.	66·2	66·7
	inter	lbs.	36·4	36·2
	low forward	lbs.	19·3	19·5
	low aft	lbs.	18·9	19·0
Mean indicated horse-power	high	I.H.P.	672	662
	inter	I.H.P.	771	764
	low forward	I.H.P.	431	428
	low aft	I.H.P.	424	418
Total power of each set		I.H.P.	2298	2272
Joint power of both sets		I.H.P.	4570	

at suitable angles; and although the cranks form practically a right-angled arrangement, with these weights fitted the steadiness of the hull and machinery at all powers is remarkable. The boilers are Yarrow water-tube, eight in number. By far the most important improvement in recent years in high-speed ship machinery has been the introduction of the water-tube boiler. This alone has rendered possible the great advances in speed; and there is little doubt that in the mercantile marine the same requirements for speed will lead to the more rapid adoption of this kind of boiler, perhaps more or less modified. The total weight of the boilers in each of the torpedo-boat destroyers is 41¼ tons, which for 4,590 I.H.P. is about 20 lbs. weight per horse-power. Although there are no separators fitted on the steam pipes, there was not the least symptom of difficulty throughout the trials, and no instance of leakage of tubes or other parts. In Table 3 are given for the sake of comparison the weights of several classes of marine engines.

TABLE 3.—*Total Weight of Machinery per indicated horse-power in various classes of vessels.*

Ordinary merchant steamer	450 lbs.
Passenger mail boat, twin screw	430 lbs.
Battle-ship or cruiser, natural draught	265 lbs.
,, ,, ,, forced ,,	195 lbs.
Torpedo gunboat, forced draught, locomotive boilers	100 lbs.
Torpedo boat, ,, ,, ,, ,,	75 lbs.
"Spitfire" and "Swordfish," forced draught, water-tube boilers	47 lbs.

Lubrication.—The engine-room of a torpedo-boat destroyer during a full-power trial is certainly not a comfortable situation. Constant attention on the part of a considerable number of men is required in order to ensure effective lubrication, and success largely depends on their ability, and on the care with which the lubricators are designed, and the pipes fitted and secured. Yet to anyone accustomed to slower-moving horizontal engines it is astonishing to see how easily well-designed and well-managed machinery of this kind gets through its difficult performance. In the early days of torpedo boats the writer had to take charge of the trials of large numbers of them on behalf of the Admiralty; and, coming as he did from the massive slow-moving machinery in the ships of war of those days, he must confess to having experienced a feeling of sheer fright on finding himself for the first time boxed up in a compartment with a set of Thornycroft's machinery running at about 650 revolutions per minute. Although these engines were then, as now, the perfection of good design and manufacture, it seemed almost impossible to get through a two or three hours' trial with machinery whizzing round at a rate which rendered the details invisible. But as time went on, and the boats were satisfactorily completed, the writer's experience was that, although boilers, which of course in those days were not water-tube, might give out, or vibrating pipes might burst, or other outside parts might break down, yet the engines themselves rarely gave trouble, or if they did it was generally in some detail connected with the lubrication. But on the lubrication a great deal depended; and to ensure success the men employed about it had to be almost acrobats in their capabilities.

Since that time the field for high-speed running has gradually widened, and the more advanced engineers have for long past been prepared to accept the fact that high speed is easily possible with safety, and have used it whenever circumstances have appeared to make it desirable. That it is desirable far more frequently than it is used is a statement which is being made frequently nowadays; and it will be useful to insist upon it here. After their thirty years' experience with high-speed engines, it was natural for the writer's firm to come into the field with this kind of engine for supplying electric light and power. Some preliminary work showed clearly that open engines were not in a position, without further development, to compete with the Willans engines so largely used in central electric stations. These engines are excellent in design and manufacture; and the single-acting cylinders and enclosed plan of lubrication render them quiet running, and easy to look after in the station. Their special claims in regard to economical performance had also to be taken into consideration. It was finally decided to combine a double-acting engine of ordinary construction with a system of forced lubrication, supplying oil under pressure to every bearing; and to enclose all the working parts, in order to prevent splash from the abundant oil-supply, and in order to keep out dirt. In the first instance a small single-cylinder engine was put in hand, and the expectations formed were more than realised by its performance. It was found, as had been anticipated, that the oil under pressure enabled the working parts, even when slack, to work without noise, and that after some months' constant working at a load considerably higher than the ordinary full load for this size of engine the bearings had not worn perceptibly. A two-cylinder compound engine indicating 300 horse-power was then completed for driving a dynamo at Messrs. Siemens' Charlton Works. After this engine had been at work continuously for four years, doing the full load required for the supply of electric power, it was opened out; and the working parts, which had not been adjusted during this period, were found practically unworn. These and other experiences gained during the same period proved that the plan of forced lubrication served most satisfactorily all the purposes of quiet and efficient running at high speed; and during the last year or two many hundreds of these engines have been turned out, from the smallest size up to 500 H.P. The increasing demand for still larger engines has led to the recent erection by the author's firm of new works for building engines of this kind up to any power that may be required.

Standard make of High-Speed Engines.—The small sizes up to about 15 H.P. are all single-crank with single or tandem compound cylinders. The smaller compounds up to 300 H.P. are of the two-cylinder "Crescent" type, as shown in Plates 68 and 69. The cranks are opposite, and a single eccentric actuates the slide valves. The oil pump is an oscillating one, worked off the eccentric, and its oscillation performs the necessary valve-action on a surface at the bottom of the pump. The pumps are therefore most simple, without either valves or packing to get out of order. The engine is indeed throughout as simple in every detail as it is possible to make it. The oil is usually drawn from the bottom of the engine casing, through strainers which can be easily removed, into pipes leading to all the bearings; but occasionally, as at Bedford, at the Charing

Cross and Strand Electricity Supply Station, at Leeds, and at other places, a complete series of reservoir tanks has been fitted, supplied by separate and independent pumps. Pure mineral oil is used at a pressure of about 15 lbs. per square inch. These two-crank engines are made triple-expansion when necessary by adding two single-acting high-pressure cylinders, tandem with the other two; and this forms one of the simplest and most effective designs that can be devised for high-speed triple-expansion engines. Formerly the engines were fitted with outside glands, only where they were used with condensers on board ship; but recently this design has been adopted throughout, in order to keep the patterns constant, and also to prevent the trouble which water from the glands causes with some kinds of oil. The oil question becomes of serious importance in central electric stations fitted with condensers, especially where water-tube boilers are used.

Vibration.—For large central stations situated in densely populated neighbourhoods the design of the steam engine employed has been determined largely by the single question of vibration. The amount of vibration which will cause a nuisance is small; and several London electric stations have incurred serious losses on account of vibrations, which at the engines themselves seem inconsiderable. Having had to approach the subject of vibration in high-speed engines for land and marine purposes simultaneously, the writer was at first led astray by assuming an equality in the conditions, which really did not exist. The vibrations in the engines themselves may be classed as follows:—first, those due to vertical changes in the position of the centre of gravity of the moving parts; second, those due to couples produced by the changing momentum in the several lines of moving parts; and third, those due to the obliquity of the connecting-rod producing retardation and acceleration of the moving parts in each line, which occur twice in each revolution.

The "Crescent" engine, with cranks opposite, Plates 68 and 69, is practically balanced against the first class of vibrations; but it has a big couple, and also vibrations of the third class. Engines with three cranks at equal angles, Plates 70 to 72, are practically balanced as regards the first and third classes, but have large couples. Now it was shown by Mr. Yarrow at the Institute of Naval Architects (Transactions 1892, vol. 33, page 213) that by balancing the effects of the couples the heavy vibrations could practically be got rid of in torpedo boats and similarly built vessels with high-speed engines. This was successfully done with a few small weights in the four-cylinder engines of the "Spitfire" and "Swordfish," Plates 64 to 67, as previously mentioned.

The conclusion therefore was hastily drawn that engines for land purposes could be similarly dealt with; and an engine was built which was absolutely balanced as far as the first and second classes of vibrations were concerned, but experience showed that buildings took up the higher-speed vibrations forming the third class; and it was finally found necessary to fit a return connecting-rod to one line of cylinders, in order to obliterate these vibrations. This expedient gave both in theory and on trial a perfect non-vibrating engine in the station. Three-cylinder engines however, with equal-angle cranks, Plates 70 to 72, in which the third class of vibrations were practically obliterated, were working in central stations without difficulty from vibration; and further investigation led to the conclusion that buildings respond to the quicker vibrations, but are practically indifferent to the heavy but slower vibrating couples which give such trouble in ships. The three-cylinder engine with equal-angle cranks, Plates 70 to 72, has consequently been adopted as the standard above 200 H.P. for central stations in densely populated districts. Similar engines are also used where a uniform turning effort is especially required: though this object can of course be attained to any desired extent in other kinds of engines also, by providing a sufficiently heavy fly-wheel.

Advantages of Forced Lubrication.—For all kinds of engines the plan of forced lubrication gives the same advantages: namely, automatic lubrication, noiselessness, economy, and freedom from wear. This is due to the working surfaces being kept apart by the film of oil forced between them. Although generally the pressure per square inch on the bearing itself is far in excess of the oil pressure used, yet the relaxation of pressure on the return stroke in a double-acting engine permits the oil at these times to be driven between the metal surfaces; and during the fraction of a second occupied by the acting stroke the film of oil cannot be squeezed out. This might indeed be readily taken for granted, and is clearly proved by the absence of wear in the large number of engines already built. It is at least obvious that the oil is in the best position to take advantage of the momentary relaxation of pressure between the surfaces, if it is itself under a pressure sufficient to push it in between the brass and the journal, so as to flood the bearing completely. If the oil is supplied by gravity alone, under the head usually given in double-acting engines, there is not sufficient time for permitting it to penetrate to any distance. In a single-acting engine under constant thrust, no such film is possible. In both the latter cases, the journal will of course be greased; but if friction and consequent wear of the journal are to be absolutely prevented, such a film of oil as the forced lubrication provides between the journal and brass is essential. The better the body of the oil, the less chance will there be of effective lubrication without adequate oil pressure. To show how the oil film should affect the economy, reference may be made to a paper by Professor Robert H. Thurston published in "Engineering" (1889, January 18, page 69), in which the friction in an engine with balanced slide-valve is subdivided as follows:—main bearings 47·0 per cent., piston and rod 32·9, crank-pin 6·8, cross-head and wrist-pin 5·4, valve and rod 2·5, and eccentric-strap 5·3 per cent. The friction of piston and rod here probably includes that of the guides, which are lubricated under pressure in the engines now described; and in addition to this it will be seen that the journal friction, which can be reduced by oil under pressure, amounts to nearly 65 per cent. of the whole. When it is borne in mind that in an ordinary engine, working at one-quarter of its full power, about 50 per cent. of the power developed is wasted in friction, it is clear that the effect on the economy by the reduction of journal friction should prove considerable at low loads; and with these double-acting self-lubricating engines, as compared with single-acting engines, it is certain that this is so. It was first pointed out by Mr. Alexander Siemens in a paper read before the North of England Institute of Mining Engineers (8 Dec. 1894, page 212), in which he compared the results of the first Belliss 300-H.P. self-lubricating engine with a Willans engine of similar power, the two working alongside each other at his Charlton Works; his results showed that the gain due to the diminished friction increased considerably as the loads were reduced.

In dealing with high-speed engines, it is impossible to avoid referring to the admirable work which has been done by Messrs. Willans and Robinson in determining the conditions for economical working under various circumstances. Their trials however were made with single-acting engines; and although the results in general will apply to any engine, the reduction of friction in the double-acting self-lubricating engine should qualify them to some extent in detail. If the lubrication is accomplishing the purpose for which it is intended, the efficiency of the engine provided with forced lubrication ought to stand out high; and that this is so for all loads has been proved by results from some hundreds of engines. By the courtesy of Professor Kennedy the author is enabled to give in Table 4 the results of a trial made by him of one of these Belliss engines, supplied to the Sunderland Corporation Electric Supply Station, which will serve as an example. Here the engine efficiency at maximum load, it will be noted, works out at 96·3 per cent. The results are also plotted as a diagram in Fig. 12, Plate 73. The following comment upon the figures in the Sunderland tests was added by Professor Kennedy:—"The most singular point about them is the extraordinary high brake efficiency of the engine, which is altogether much higher than anything I have previously found. I do not know the special cause of this. I have been extremely suspicious of the figures, and have had everything checked repeatedly. The different figures taken at different periods are quite consistent with each other, and there is nothing in the records to suggest error, except the figures themselves. I can only place these on record, without saying more about them." There is no doubt that the efficiency is remarkably high; but the conditions, as already pointed

TABLE 4.—*Trials of Belliss* 200 *H.P. Quick-Revolution Self-Lubricating Engines, Condensing. See Plates* 73–4.

Cylinders 12¼ and 20 inches diameter, with 9 inches stroke. Working pressure 120 lbs. per square inch above atmosphere.

Station	Sunderland Electric-Supply Engine, tested by Professor Kennedy. Fig. 12.						Cheltenham Electric-Light Engine, tested subsequently. Fig. 14.			
Load	Maxi-mum.	Normal full.	Three quarters.	Half.	One quarter.	Only ex-citing.	Normal full.	Three quarters.	Half.	One quarter.
Mean effective pressure per sq. inch reduced to low-pressure cylinder } lbs.	42·3	37·6	28·6	20·0	9·7		36·1		20·6	10·4
Mean revolutions per minute. . . revs.	364·6	365·0	364·5	363·9	363·8		365·5		361·0	361·5
Mean Indicated horse-power . . I.H.P.	217·5	193·6	147·1	102·7	49·8		185·7		104·8	53·1
Mean Brake horse-power . . . B.H.P.	209·5	186·0	140·6	97·0	44·5		176·8		97·4	44·2
Mechanical Efficiency $\frac{\text{B.H.P.}}{\text{I.H.P.}}$ per cent.	96·3	96·1	95·2	94·4	89·3		95·2		93·0	83·2
Water per hour, total . . . . . . lbs.	3772	3383	2628	1920	888·5		3301		1939	987·9
" " " per B.H.P. . . . lbs.	18·0	18·2	18·7	19·8	20·0		18·6		19·9	22·3
	Coupled to Continuous-Current Dynamo. Fig. 13.						Coupled to Alternator.			
Mean effective pressure per sq. inch reduced to low-pressure cylinder } lbs.		36·0	24·2	19·2	10·5	2·2		28·4	23·0	
Mean revolutions per minute . . revs.		367·6	365·3	362·6	365·2	364·8		350·2	351·0	
Mean Indicated horse-power . I.H.P.		186·7	129·4	98·2	54·1	11·6		144·8	114·4	
Mean Electric horse-power . . E.H.P.		168·6	115·1	83·8	40·9			126·8	98·5	
Combined Efficiency $\frac{\text{E.H.P.}}{\text{I.H.P.}}$ per cent.		90·3	88·9	85·3	75·6			87·5	86·1	

out, all tend in this direction, and similar results have been proved over and over again with the self-lubricating engines tested at the author's works. In order however to establish the results obtained by Professor Kennedy, a further trial was conducted with a similar engine made for the Cheltenham Electric Light Station from the same drawing as that at Sunderland; and it will be seen that the results given in Table 4, and plotted in Fig. 14, Plate 74, entirely bear out those of the other trials. The high efficiency that can thus be obtained makes itself felt in the economical working of the engine; and as it is due to an absence of friction, a far greater saving will probably arise from the diminished necessity for adjustment and repair on account of wear. In the writer's opinion there is at present too much difficulty in obtaining the necessary accuracy in indicating a high-speed engine to render the indicated horse-power alone a useful standard for comparison of efficiency. The consumption of steam for work done is what the customer looks at; and results given per indicated horse-power, which take no account of the heavy losses through friction, are useless in comparing engines of different kinds. It will be seen from Fig. 13, Plate 73, giving the curves of the combined efficiency and consumption in the subsequent tests of the Sunderland engine coupled to a continuous-current dynamo, that the previous brake tests are fully borne out. These subsequent tests were made immediately after the others, in the presence of Professor Kennedy, and Mr. Snell, the electrical engineer to the Sunderland Corporation. The results throughout are undoubtedly good; and for the sake of comparison curves have been added showing the consumption and efficiency of a Willans engine of about the same power combined with a Holmes dynamo, in a trial made by Professor Kennedy and reported in "Engineering," 2 June 1893, page 783.

Governing.—Amongst the many admirable papers emanating from Messrs. Willans and Robinson on the subject of high-speed engines is a recent paper read to this Institution by Captain Sankey (Proceedings 1895, page 154), in which governing by expansion-valve is compared with ordinary governing by throttle-valve. This important contribution to the subject is chiefly remarkable for the tendency of the results presented to displace the expansion-valve governor from the high position it has hitherto held as an economical appendage for reducing power. The disadvantages due to the higher initial pressure with consequent leakage, the frictional loss due to compression, and the increased losses due to liquefaction, are clearly pointed out; and the resulting efficiencies of the two modes of governing, especially when determined by work done and not by indicated horse-power, are shown to be not greatly in favour of the expansion-valve governor. Expansion gear of this sort is also far more liable to wear; and a small amount of wear, or of wrong adjustment after repair, might lead to a steam distribution yielding at low loads considerably worse economy than that obtained in the official trial at the works. As in the case of economical results, the comparative efficiency of the two methods of governing will also depend in detail somewhat on the kind of engine; and for this reason the trials that have been made by the author for determining the value of the two kinds of governor with the self-lubricating engine may be of interest. The results given by Capt. Sankey are also based entirely on the indicated horse-power; but as the output of the engine is largely modified by frictional and other losses due to the action of the governor itself, the indicated horse-power results are of little practical value. The circumstance that the "Crescent" engine, Plates 68–9, is arranged with both the valves driven by a single eccentric naturally led in the direction of expansion governing, owing to the ability of this governor to act simultaneously on both high and low-pressure valves. Trials made in 1891 with a number of sets of dynamo machinery of about 80 horse-power, constructed by the writer's firm for the Cunard steamships "Campania" and "Lucania," gave excellent results as far as governing went; but at low powers the results in respect of economy and efficiency were by no means as good as anticipated; and although in consequence of its effective action the use of the governor was continued, the poor economical results led to special trials being made further on for determining this point more exactly. So far as the governing itself is concerned, since the above machinery was built, the throttle governor with ordinary fly-wheel has been made by the reduction of friction to give exceedingly steady results, with a permanent variation of only 2 to 3 per cent., and a momentary run-up to about 10 or 12 per cent. when all the load was suddenly thrown off. With the ordinary fly-wheel it is not possible to get much finer governing without introducing a tendency to hunt. The effect of a large fly-wheel permits the fitting of a much more sensitive governor; and with a fly-wheel of suitable dimensions governing by throttle can be made as fine and steady as may be required. Alternators of ordinary design have of course in themselves quite enough fly-wheel effect for enabling the usual engine fly-wheel to be dispensed with; and with these there is no difficulty in keeping the run-up below 5 per cent., with permanent variation of 2 per cent. The reputation of the expansion-valve governor has been much increased by the value set upon it in the United States, where it is almost universally used; but this fact is largely qualified by a consideration of the high fly-wheel effects employed in conjunction with the governor in order to obtain the maximum results. The following Table 5 gives a few typical examples for enabling a comparison of these fly-wheel effects to be made for various services. For the Waterloo and City Railway, where it is desired to light the trains steadily, direct from the motor currents, a fly-wheel of about 5½ tons has been fitted on each of the 300-H.P. sets in order to obtain the required results, namely permanent

TABLE 5.

Energy stored in Fly-wheel and revolving parts of Dynamo per electric horse-power at full load, for various services.

	Foot-Tons.	Revs. per min. of engine.
Ordinary High-Speed Engines for electric lighting with continuous-current dynamos	0·2 to 0·3	350
Ditto, with heavy alternator	1·5 to 3·5	360
Electric Traction, Continental example . . .	2·0	150
,, ,, Montreal Street Railway . .	4·0	70
,, ,, Brooklyn Electric Tramway .	4·7	75

variation not exceeding $1\frac{1}{4}$ per cent. and momentary not exceeding $2\frac{1}{2}$ per cent. when all the load is suddenly removed. As far as governing is concerned therefore it may be allowed that the advantage, if any, is on the side of the throttle-valve governor, because it is equally powerful in governing, far less liable to derangement and wear, and much easier to adjust.

In respect of economy, the matter will naturally be looked at from two points of view:—firstly for electric lighting and electric power supply, where the maximum economy is required at about full load; and secondly for electric traction, where the normal load will probably be a much smaller fraction of the full load than in electric lighting. For electric lighting and power supply, there is no question in the author's mind as to the superior efficiency of the throttle-valve governor. For electric traction, his experiments seem to show that with the double-acting self-lubricating engine there is little if any benefit to be derived from the expansion-valve governor; and this benefit will probably be neutralised by the mechanical difficulties, which the extra wear on the expansion governor will subsequently entail. To determine this point a number of experiments have been made, of which the results are shown in Table 6 and in the curves in Fig. 15, Plate 74. These trials were made with a self-lubricating engine of 250 horse-power, fitted with an expansion governor actuating an eccentric common to both valves. The curves XX show the results with the expansion governor, and the curves TT the results from the same engine when governed by the throttle valve. It will be noticed that, whilst the expansion-valve governor has a slight advantage when indicated horse-power is considered, the advantage is all on the side of the throttle valve when the output or electric horse-power is considered; and this of course is the only matter of importance in practice.

From all the diagrams it will be seen that the characteristic curve of water consumption for the Belliss engine is more horizontal than those for single-acting engines. This is due, as already pointed out, to the action of the forced lubrication in reducing the amount of friction, and consequently the amount of steam used per brake horse-power. In order to elucidate this point more fully, there is added

TABLE 6.—*Comparative trials of Belliss 250 H.P. Quick-Revolution Self-Lubricating Engine, Condensing, when governing by Expanding and by Throttling. See Fig.* 15, *Plate* 74.

Cylinders 12 and 20 inches diameter, with 10 inches stroke. Boiler pressure 150 lbs. per square inch above atmosphere.

Governing by Expansion Governor or by Throttling.		EXPANDING. Expansion Governor *in* action.				THROTTLING. Expansion Governor *out of* action.			
Load		Full.	Five eighths.	One third.	One quarter.	Full.	Five eighths.	One third.	One quarter.
Mean effective pressure per sq. inch reduced to low-pressure cylinder	lbs.	41·0	27·0	16·4	12·4	40·1	25·9	15·7	10·9
Mean revolutions per minute	revs.	370	373	380	380	370	370	380	382
Mean Indicated horse-power	I.H.P.	240·9	161·0	99·0	75·3	235·4	152·2	95·0	66·2
Mean Electric horse-power	E.H.P.	213·0	132·8	77·8	53·0	213·0	132·2	77·8	53·0
Combined Efficiency $\frac{\text{E.H.P.}}{\text{I.H.P.}}$	per cent.	88·3	82·4	78·5	70·3	90·4	86·8	81·9	80·0
Water per hour, total	lbs.	4579	3041	2209	1818	4473	2871	1992	1505
„ „ „ per E.H.P.	lbs.	21·5	22·9	28·5	34·3	21·0	21·7	25·6	28·4

in Fig. 12, Plate 73, for comparison with Sunderland, as shown by the dotted lines, the consumption per brake horse-power for a Westinghouse engine of about the same power, fitted with an expansion-valve governor, for which the data are taken from the Proceedings of the Institution of Civil Engineers, vol. cxiv, page 68. It will again be seen that, while with the expansion governor in the Westinghouse engine the result at half load is better than at full load, it is not better than the result obtained at half load with the throttle governor in the Belliss engine, which has moreover a decided advantage at full and low loads.

For the sake of further comparison another curve has also been added to Fig. 12, Plate 73, showing the efficiency of the Willans 150 H.P. engine, reported in the same volume of the Civil Engineers, pages 89–90.

Discussion.

Mr. Morcom called attention to the additional diagram shown in Plate 75, which, though altogether a hypothetical diagram, would serve to illustrate what had been referred to at the end of the paper (page 330): namely that, in an engine in which the constant friction was low owing to forced lubrication, the curve of water consumption per brake horse-power was more horizontal than when the friction was higher. Here the thin curve A A represented the consumption in a single-acting engine with throttle governing; the thick dotted curve X X pertained to the same engine with expansion governing; and the thick full curve L L to the double-acting self-lubricating engine with throttle governing. The larger area B D E consequently showed the advantage of expansion governing over throttling in single-acting engines; while the much smaller area C D E showed the much smaller advantage of expansion governing in the single-acting engine over throttle governing in the double-acting self-lubricating engine.

Mr. JOHN I. THORNYCROFT, Member of Council, said the paper dealt with a subject which had occupied his attention a great deal; and he thanked the author for the complimentary allusions to the work of his own firm. When he had himself commenced working with engines of rapid rotation, he had been led to use engines which made a large number of reciprocations per minute, because the particular work he had to do rendered it necessary to have as light an engine as possible. From what had now been stated in the paper it appeared that, with the plan of forced lubrication here described, not only could a light engine be made an economical engine, but it could also be made a durable engine. He therefore thought that, owing to the economy and reduction of space thus realised, there was a great future for rapid rotating engines. The effect of high-pressure lubrication, in enabling double-acting engines to do work which it had been considered could be done with advantage only by single-acting engines, was a great gain if it could be accomplished, as he believed it could be, because it increased the quantity of work that could be got out of a given weight of material; a double-acting cylinder did double the duty of a single-acting of nearly the same weight. A journal must necessarily have a little freedom in its bearing, and although the relaxation of pressure in the return stroke was for so short a period, the oil being under considerable pressure was able to force its way in, first on one side and then on the other, and to cover the whole rubbing surface effectually with a film which could hardly be displaced in the short time occupied by the acting stroke. It was desirable to use all the pressure that was practicable, provided that too much power was not wasted in pumping the oil. With the rapid flow of oil through the circulation, it appeared to him that any dirt it contained might be likely to go round and round, and do repeated damage; and he suggested that it would be an advantage if more storage space were allowed, so that the oil might have some time to settle. In a land engine it would not be a considerable space that would be required; nothing like so large as was desirable in the boiler, but a sufficient space where any sediment could fall. Oil filters also were now used. In a gas-engine which he had running, the oil

(Mr. John I. Thornycroft.)

went round and round, passing through the filter in each circuit. Although it appeared dirty as it came from the engine, it went back again clean into the circulation; and no trouble was found in using it over and over again, he did not know for how long. If something of that sort could be combined with the forced lubrication in the rapid rotating engine, he thought it would be an advantage.

He asked what was considered by the author to be a reasonable factor of safety, such as was referred to in the first page of the paper.

Professor W. CAWTHORNE UNWIN considered it highly interesting that journal friction, which seemed for so long to have been generally looked upon in a rather theoretical kind of way, should at last have been dealt with in such a practical manner as to lead to so great an improvement in the working of engines. In Table 5 (page 329), in which the energy stored in the fly-wheel and revolving parts of the dynamo was given per electric horse-power, it would add he thought to the interest and instructiveness of the information if the energy could also be stated on the basis of the work done in one revolution. [See page 360.]

Mr. BRYAN DONKIN, Member of Council, criticized the unqualified use of the designation "high-speed" in the title of the paper inasmuch as the piston speed of 550 to 640 feet per minute in Tables 4 and 6 was not a high piston-speed, but rather a low one. The term "rapid rotating" would perhaps be more correct for these engines. In mill engines the piston speed was from 600 to 700 feet per minute; here it was only from 550 to 640 feet per minute. The tendency at the present time he supposed was to shorten the stroke and increase the rotative speed, with a view to greater economy. The high mechanical efficiency was remarkable. It would be interesting to have an experiment made on the same engine, if possible at the same speed and the same load, at first with the forced lubrication, and afterwards without it, that is, with only the old-fashioned lubrication. This could be done either without steam in the cylinders, or with steam in them; the latter of course would be preferable in order to make the experiment truly comparative.

Respecting the two-cylinder compound engine at Messrs. Siemens' Charlton Works, which had worked continuously for four years (page 321), he asked what was the number of hours per day or the number per week; was it running practically all day?

Mr. WILLIAM BROWN, manager of the works, replied that the engine had been running for about four months from six o'clock on Monday morning until one o'clock on Saturday, without stopping. Generally it ran from 10½ to 11 hours per day.

Mr. J. HARTLEY WICKSTEED, Vice-President, asked for an explanation of how it came about that governing by the expansion valve was better when the water consumption was measured per indicated horse-power per hour, whereas governing by the throttle valve was better when the electric horse-power was made the basis for the comparison (page 330).

Mr. A. TANNETT WALKER, Member of Council, was glad to have been one of those who had visited the works of Messrs. Belliss on the previous day; and he had been greatly delighted with the work he had seen being there carried out. What had struck him most with regard to it was the smallness or thinness of the material, the beautiful castings, the fine work, and the little space occupied by the engine when it was complete. It had also been impressed upon his mind that, when there was such good material and such good workmanship, and when an engine had been so well put together, it was of the utmost importance to respect the good material and the good workmanship by keeping the engine clean; and it was impossible to keep it clean and free from friction unless the oil were forced to flow all over the surfaces that were rubbing together under pressure. This matter he felt much indebted to the author for having emphasized in the paper, from which he thought a good lesson might be learnt. In regard to the piston speeds, he remembered his firm many years ago making for the President an

(Mr. A. Tannett Walker.)

engine of six feet stroke, indicating from 3,000 to 4,000 horse-power, which had a piston speed of 1,200 feet per minute, and the bearings did not get hot.

Mr. R. E. CROMPTON thought that, when such a valuable paper as the present had been prepared for the Institution, it was only fair that in the discussion those who had used these engines successfully to a considerable extent, as he himself had done, should say something about them. From his own experience he could say nothing but good of them. While he was himself in favour of what he considered were rightly called high-speed engines, he gathered from remarks which he frequently heard made that there was still lingering in the minds of some mechanical engineers the idea that there was something novel, something yet untried, in high-speed engines as compared with the slower and heavier make of engines formerly used. As perhaps almost the first user of large high-speed engines, he might deal from practical experience with such a question as that of how many hours they would run continuously. From the question itself it would appear that there was still a lingering idea that long hours of running proved a difficult test for an engine. Tested in that way he could state that no engines in the world had run such long hours as high-speed engines. High-speed colliery engines he knew were running year and year about, and stopping only for a few hours for cleaning during the Christmas week. There were also many cases that he knew of high-speed engines employed in electrolytic work which ran continuously, stopping only during the Christmas week. Professor Kennedy would no doubt corroborate the statement that modern well-constructed high-speed engines, of which the Belliss engine was a leading example, could be worked with only one cleaning down and general over-looking in the year. Such a result had been arrived at after twelve years' continued development, so that this kind of engine could no longer be considered in its initial stage. Where steam engines of large power were required for meeting the great modern development of large central electric-power stations, the high-speed engines had deservedly won their position, and he believed they would gradually supersede low-speed engines, because not only was there so much less material in them, but also they required no larger quantity of good workmanship than the others. In every respect, in economy of fuel, of water, and especially of lubricants, and in a further economy of the labour and attendance required to start and take care of them, high-speed engines possessed such important practical advantages over others, that the engineers of large electric-power stations were continually finding there was no comparison between the old slow-running engines and the high-speed engines in doing the largest amount of work at the lowest cost. The papers that had appeared from time to time from Mr. Willans and others, and now from Mr. Morcom, on high-speed engines, he always kept beside him as most useful works of reference; they were undoubtedly of the highest value.

Sir Edward H. Carbutt, Bart, Past-President, had yesterday had the pleasure with a large number of other members of going round Messrs. Belliss' works, and had been much struck with their new construction of high-speed engines pumping in oil under high pressure, and enabling them to arrive at the result pointed out by Mr. Crompton, so that if these self-lubricating engines would run for an hour they would run for a year. It would be remembered that something of the same kind had formerly been experienced with rolling-mill engines, of which it had rightly been said that, if they could roll only a short length, say a few inches, they could roll a mile, or as great a length as the material would allow. The corresponding fact with regard to these high-speed self-lubricating engines had been thoroughly brought out by the present capital paper, for which he considered that the members were greatly indebted to the author, and for the many valuable facts he had placed before them. In regard to the vibrations emanating from large central electric stations situated in densely populated neighbourhoods, he had mentioned at the Belfast Meeting last summer (page 333) that at the St. James' electric station in London considerable trouble had been experienced from vibration, though not in the immediate neighbourhood of the station. It had been found that, when two engines were running

(Sir Edward H. Carbutt, Bart.)

together synchronously, the vibration would be started in some of the clubs as much as two hundred yards away, being transmitted all through the foundations; the windows at some distance off would shake, showing that the vibration set up at the engines was carried underground to that distance. A great deal of work he believed had had to be done in putting in new foundations; and even these had hardly proved successful for satisfying the clubs that there was not a nuisance. If the difficulty of vibration could be overcome by such engines as were described in the paper, these would be of great benefit to electric-lighting stations.

Professor ALEXANDER B. W. KENNEDY, Past-President, had come to Birmingham not only for the purpose of attending the present meeting, but also in order to have an opportunity of going to Messrs. Belliss' works, with a view to inspecting one of their engines with which the author had undertaken to produce, with a throttle governor, results of a somewhat unusual kind. The statements with which his own name had been connected in pages 325–7 of the paper were perfectly correct. The brake efficiency of the particular engine used in Sunderland was so high as to render him at first strongly suspicious of some mistake, and he did his best to cross-examine all his own records as well as the author's; he had not been able however to find any mistake in them. The figures appeared to be consistent, and he could only conclude that the engine really had an unusually high brake efficiency. Although on that occasion the brake efficiency was higher than he had ever found in any previous tests of the same kind of engine, it had since been repeatedly found that exceptionally high brake efficiencies had been realized. This he did not doubt was due to the fact that the engine was double-acting, the plan of forced lubrication having rendered the use of such an engine practicable. As to the suggestion (page 334) that one of these engines should be run at full load without the forced lubrication, he should certainly feel some hesitation about it himself, and in any case should not like it to be done with any of his own engines. Engineers he thought were indebted to Messrs. Belliss for their insisting on working down to brake horse-power, in addition to the common practice of working through to electrical horse-power. Naturally for the purposes for which so many of these engines were used the main result wanted, as mentioned in the paper (pages 330–1), was the combined efficiency or ratio of electrical to indicated horse-power. At the same time it was important to get at the mechanical efficiency or ratio of brake to indicated horse-power; otherwise it could not be seen whether a high combined efficiency was due to a particularly good dynamo or to a particularly good engine. In emphasizing the necessity for obtaining the measurement of brake horse-power, the author was probably stimulated by the remarkably good brake efficiency attained with the self-lubricating engines. A statement of efficiency in terms of pure mechanical engine efficiency or brake horse-power was specially important when it was seen from the diagrams exhibited that the extra indicated horse-power obtained per lb. of water by means of forced lubrication might be all used up in working some special apparatus which possibly was not wanted. Whether this were so could only be ascertained by analysis, with the help of brake trials such as had been carried out by the author.

There had been some places in London where high-speed engines of various kinds had caused considerable vibration: the St. James' electric station in Pall Mall, referred to by Sir Edward Carbutt (page 337), was one. In that instance however he believed there was no doubt that the vibration had been due to an imperfectly designed foundation; and he was afraid that neither the use of the Belliss engines nor of any others would have prevented vibration. Another serious case which he had had occasion to consider carefully had been due, he had no doubt, to the fact that a somewhat badly designed foundation block had been placed on what had afterwards been found to be the site of an old river bed; and the vibration was in some way communicated by underground water to places at a distance of some hundreds of yards, to an extent which really amounted to an intolerable nuisance.

He could thoroughly confirm what had been said by Mr. Crompton (page 336) about the way in which high-speed engines, both of the Willans and of the Belliss kind, would run day after

(Professor Alex. B. W. Kennedy.)

day and year after year continuously, with a minimum amount of looking after or repair. He had a number of Belliss engines at work, and he knew nothing about the inside condition of them, nor did he trouble himself about it. They would run for twelve months continuously, and then required to be cleaned. It was just the same with the Willans engines: under ordinary circumstances nothing whatever was known about their internal arrangement, nor about the main bearing brasses. When the slack time came in the summer they were opened up and cleaned, when piston rings could be renewed and other such matters attended to. Both of these high-speed engines did a great amount of hard work, as was well understood by everyone concerned with electric lighting, and still more with electrolytic work; and they did it at an expense in maintenance and attendance which was ridiculously small. The present paper formed in his opinion a valuable addition to the literature of high-speed engines, a literature which had been of singular value already.

Mr. ALFRED SAXON said that, while undoubtedly there was a field for high-speed engines, he had noticed in going through Messrs. Belliss' works on the previous afternoon—and he desired to express his obligations for the opportunity of seeing them—that a beginning was just being made there in building engines of a larger size; and it was with these he thought that difficulties would now be likely to be met with, in competing with ordinary Lancashire mill-engines for economy. All the comparisons that had been presented in the diagrams exhibited were comparisons of high-speed engines with other high-speed engines. The result however would be different if a comparison were made with some of the best Lancashire mill-engines for economy and efficiency: apart at least from brake efficiency, because it had been clearly proved that the plan of forced lubrication was of great advantage in producing the remarkably high brake efficiency obtained from the Belliss engine; but for water or steam consumption the latter he thought would not compare favourably with the best Lancashire mill-engines. In all high-speed engines there were features which militated against their economy, particularly the somewhat higher percentage of clearance in the cylinders. In the large mill-engines the chief improvements of late years had been brought about by a reduction of cylinder clearances. The waste due to excessive cylinder clearance on account of the high speed of rotation seemed to him therefore to be the great difficulty which would have to be overcome in high-speed engines. The slower revolutions of large mill-engines, even with a high piston-speed, were attended with less waste by cylinder clearance because the number of steam admissions was fewer in the same time. The more frequent admissions formed one of the great disadvantages in high-speed engines, which for the larger powers he considered would consequently compare unfavourably with the best commercial engines for mill purposes. The latter had also been introduced in some instances for electric lighting, particularly in Manchester. The choice between the two kinds of engines fcr large powers he believed would depend upon whether the high brake efficiency of the self-lubricated engine would assist it as a high-speed engine in competing with the higher economy of the slower-revolution engine in respect of steam consumption.

Professor JOHN GOODMAN said it was particularly interesting to those who had worked at the subject of lubrication to find the remarkably high mechanical efficiency which had been obtained by means of forced lubrication. At the time when the Reports were presented of the Research Committee on Friction (Proceedings 1883–85–88–91) he remembered hearing it asked, what was the use of recommending bath lubrication, which could not be obtained in practice? Here however was now an admirable illustration of the practical value of the experiments then made by Mr. Tower for the Institution. In the present paper was exemplified a practical method of applying bath lubrication to a high-speed engine; and he therefore thought the Institution was greatly to be congratulated upon the research work that had been done by the Friction Committee, which had proved so extremely valuable in practice.

One reason he believed why the engine now described gave such high mechanical efficiency was that white metal was used in all the bearings instead of brass. Having done a good deal of experimental work during the last six years with different kinds of white metal for bearings running under high pressures, he had found that the coefficient of friction with even the worst of them was considerably lower than with the very best brass or phosphor-bronze or hard gunmetal. The true reason he believed to be that when the engine or machine was working there must be some spring in the shafts and in the bearings, however slight. If the bearings were made of a hard material, like phosphor-bronze or brass or gunmetal, it was like sitting on the sharp edge of a hard chair; but with bearings of soft white-metal it was like sitting on the edge of a well-padded chair. This illustration represented what he thought really took place in the working of machinery. When the spring occurred in a shaft, the whole of the load came on one edge or at one end of the bearing. White metal allowed the pressure to be distributed more evenly than it would be distributed on a harder metal. A mechanical efficiency of 94 per cent. he had previously heard of as having been obtained with an engine fitted with white-metal bearings, tested by Mr. Wilson Hartnell of Leeds.

An interesting point in the diagrams was the parallelism of the lines representing indicated horse-power and brake horse-power: thus showing that the power required to drive the engine itself was practically constant at all loads. In years gone by this had sometimes been regarded as a mere theory; but here was an admirable instance of the interval between the two lines of indicated and brake horse-power being practically constant. Such a result he believed was largely due to the fact that the lubrication was so excellent. If there were poor lubrication, these two lines would not be parallel.

It would be of great value and interest if the author would give the working pressures per square inch on all the bearings, both the crank-pins and the rest of the rotating bearings; and also the surface speeds of those bearings. He asked also what quantity of oil was used; how would it compare during a year's running with the quantity of oil used in the ordinary way? The engine being boxed in and flooded with oil, he should imagine that the quantity of oil used under these circumstances would be much less than with the ordinary mode of oiling bearings. In a double-acting engine it had been pointed out in the paper (page 324) that the reversal of pressure on the bearings permitted the film of oil to be maintained between the bearing surfaces, because there was not time for it to be squeezed out in the acting stroke. In some experiments which he had been recently making on this very point, he had made use of a friction-testing machine in which the whole load could be suddenly applied, and the friction automatically recorded. The machine was allowed to run with the lever propped up, so that the bearing was practically under no pressure; and the friction line was recorded on the drum, which was revolving rapidly. Then suddenly the lever was dropped, and a load of about 1,000 lbs. per square inch was brought upon the bearing. It was thus found that it took from two to three seconds before the full friction came upon the bearing; the interval depended somewhat on the viscosity of the oil. Roughly speaking, the thicker the oil, the longer was the time it took; and the thinner the oil, the shorter the time before the bearing felt the full friction. It was distinctly seen that it took from two to three seconds for the friction to get to the maximum; and this of course represented the time taken in squeezing the oil out from between the rubbing surfaces.

In the balancing of the engine referred to in page 323 he enquired what was meant by the return connecting-rod which it had been found necessary to fit to one line of cylinders in order to obliterate the vibrations.

Mr. **Morcom** explained that it was like the return connecting-rod employed in the old marine engines of the Maudslay build, in which the crank shaft had been so close to the cylinder that a pair of piston-rods had to be carried to a cross-head on the far side of the shaft, whence a return connecting-rod was brought back to the crank.

Mr. **William Sisson** agreed with Mr. Donkin (page 334) in wishing if possible to know what was the difference in friction between the engine running with forced or pumped lubrication, and the same engine running with the ordinary bath lubrication. The friction experiments conducted for the Institution by Mr. Tower

(Mr. William Sisson.)

had opened the eyes of engineers to the practical requirements of lubrication, and had been of the utmost value. They had shown that bath lubrication—not indeed forced lubrication by pumping, but free washing lubrication—gave an average coefficient of friction about one-sixth or one-seventh of that obtained with good siphon lubrication. The point was whether an oil pressure of 15 lbs. per square inch, which was admittedly far below the pressure per square inch on the bearing surfaces, made much difference in regard to efficiency of lubrication: whether ordinary bath or free washing lubrication would not be almost equally efficient, if not quite so. This was what he imagined many engineers besides himself would like to see tested. It would be remembered that an interesting experiment had been tried by Mr. Tower with a rotating journal having a brass on the top, the lubricant being supplied by a bath on the under side (Proceedings 1885, page 58). A number of small holes were pierced through the brass to the bearing surface, and a pressure gauge was connected with them successively, which was found to indicate practically the pressure per square inch on the actual surfaces in contact. Those experiments showed that, even without forced lubrication by a pump, oil might be got in freely, and would flow in to such an extent as might be required, whatever might be the pressure on the bearing within the limits of the experiments. In his own experience with some high-speed engines he had met with something that seemed to point in the same direction. In the crank-shaft bearings of a double-acting engine the oil was forced back up the vertical pipe of the sight-feed lubricator to a height of 4 or 5 inches above the top of the bearing surface (compare Proceedings 1883, page 638). As shown by Mr. Tower's experiments the oil must be supplied at a place where there was no pressure: it was useless to attempt to put oil in on the pressure side; it must be supplied on the slack side.

The unequal pressure on a bearing in working, to which attention had been called by Professor Goodman (page 342), seemed an important point; because, whatever might be the strength of the shaft or the journal used, there must be more or less spring or yielding when it took the load. Instead of putting in a soft metal, which could be compressed but would not return into place, a better plan he suggested was to make the pedestal or bearing swivel or spring, much in the same way as the armature-spindle bearing of a dynamo was held, and to let the brass overhang considerably at each end. This he believed would be found to be an excellent plan to carry out, to allow of the necessary spring of the shaft or journal. Having himself had some experience in carrying it out with double-acting high-speed engines, he had found that it worked well. The bearing of the brass on the shaft might be perhaps three times or at least twice the length of the support of the brass in the frame or pedestal; and it seemed to accommodate itself well to the shaft by means of the slight swivelling movement.

With regard to governing, he was afraid that many engineers besides himself were obliged to differ to some extent from the author. The difficulty in depending on throttle governing alone was that, in an engine with a variable load, which might be called upon to exert a high power for a short time, say for example only one hour in the week, the cut-off must be so late as to suit the minimum boiler-pressure that could be depended upon. It seemed clear, as had been pointed out in Capt. Sankey's paper (Proceedings 1895, page 168), that at the beginning of a reduction of load automatic-expansion governing ought to be employed down to a certain point, which had to be determined by experiment; below this load the regulation ought to be continued and completed by throttle governing. It would appear that such an arrangement ought to give the best results. There could be no doubt that, as had been pointed out both by the author of the present paper and previously by Capt. Sankey, to continue governing by automatic expansion down to the lowest load was rather a cruel thing to the engine; as Mr. Crompton had recently said, it banged the engine about. Government by the cut-off was wanted at the beginning when coming down from the full load, especially if the engine was adjusted to work up to an overload; from the overload downwards the governing ought to be by automatic expansion down to half load or some other determined point. With regard to the

(Mr. William Sisson.)

trustworthiness of shaft governors controlling the expansion, he could not see that there was any more difficulty in making a shaft governor trustworthy for regulating the expansion than for controlling the throttle valve. A great number of shaft governors that he had known had worked for many years without adjustment. They might be designed so as to give ample power, with large surfaces and with arrangements for oiling; and he believed they could be depended upon fully as much as throttle governors. With a shaft governor directly controlling the distribution valves it was almost impossible for an accident to take place by reason of the engine running away, because there were so few working parts in the governor that there was hardly anything to get out of order; and if a spring broke, the weights flew out and shut off the steam. Engines with ordinary shaft governors he knew had been running twenty hours a day for three or four years; nothing except occasional cleaning had been done to them, and they were running now as well as ever. For electric traction, where the average load was probably a much smaller fraction of the full load than in electric lighting, expansion governing was particularly required; but the best arrangement was the combination already mentioned of expansion and throttle governing.

Personally he desired to thank the author's firm for the privilege he had enjoyed in visiting their works. It was a generous act on their part to permit so many who might be competitors to see their works, and he desired heartily to acknowledge the privilege.

Dr. John Ryan asked whether in the first class of vibrations dealt with in page 322 it was sufficient to consider such changes in position of the centre of gravity of the moving parts as took place in the vertical direction only. The three classes enumerated he supposed were not considered to be exhaustive. Vibrations due to faulty workmanship and design were probably considered to lie outside the scope of the paper, as they doubtless lay outside the practice of the best engine builders. With the statement that a small amount of vibration might develop into a nuisance, as instanced by Sir Edward Carbutt (page 337), he fully sympathised, because in University College, Bristol, though he had only a slow running engine, making about 140 revolutions a minute, he was worried by people who complained of the effects. It was astonishing how sensitive some people seemed to be to mechanical movements of one kind and another; and it was perhaps not surprising that vibrations were detected sixty yards away, which were wholly unnoticed in the immediate vicinity of the engines by those more used to the working of machinery. The question of preventing synchronism in engines was likely to be of importance, inasmuch as the unpleasant vibration experienced must be largely due to agreement of the impulses with the period of vibration of some of the parts or connections; and it might be necessary, if speed of revolution went on increasing, to "tune" the engine and its connections by modifications in design, so as to prevent the vibrations from being carried, as at present they undoubtedly were in certain instances, to a considerable distance from the engines. A good deal naturally depended on the foundations; and if these happened to be placed, as in the instance mentioned (page 339), on an old river-bed or a water-bearing subsoil, extreme effects would of course be produced. His own experience hardly agreed with the author's conclusion (page 323) that buildings picked out only the quicker vibrations; for unfortunately the college buildings in Bristol seemed with singular perversity to respond to all kinds of vibrations.

Professor WILLIAM RIPPER agreed with the remark made in page 327, that there was at present too much difficulty in obtaining the necessary accuracy in indicating a high-speed engine to render the indicated horse-power alone a useful standard for comparison of efficiency. For indicating high-speed engines he had himself lately used a simple device, which, although it was only approximate at slow speeds, became more and more accurate as the speed of revolution of the engine increased. As shown in Figs. 17 to 20, Plate 76, it consisted of two barrels, in each of which was a piston valve working over ports in the barrels. Each barrel was surrounded by a chamber, which was connected to a pressure-gauge for recording the pressure of the steam entering the chamber. The valves were arranged to work so

(Professor William Ripper.)

that the chamber surrounding one barrel was connected continuously with the steam or impulse side only of the piston, while the chamber surrounding the other barrel was connected continuously with the exhaust side only. The mean pressure in the first chamber was the mean pressure on the steam side of the piston; and in the second chamber the mean pressure on the exhaust side. The difference between these two pressures was the mean effective pressure on the piston. The oscillations of the fingers of the gauge were reduced to a minimum by throttling down the gauge cocks, as was now done with the gauges on the receivers of compound engines, and with vacuum gauges. Either two separate gauges might be used, or a single differential pressure-gauge, from which the average difference of pressure on the two sides of the piston could be read directly. The higher the speed of the engine, the less was the angle of oscillation of the gauge pointer, and the less the need for throttling the gauge cocks in order to read the mean effective pressure. The action of the piston valves was as follows, I being the impulse-steam valve, and E the exhaust-steam valve. The pipes leading from each end of the engine cylinder entered the indicator as shown in Figs. 18 and 19; one end of the engine cylinder was connected with the passage AB, and the other with the passage CD; and these passages were so arranged that each connected one end of one indicator barrel with the opposite end of the other barrel. The valves were shown in mid-position, which was their correct position when the engine piston was at either end of its stroke. Both valves moved together, and were worked by the same lever. Supposing steam was being admitted to the top end of a vertical cylinder when the piston was at the top of its stroke, then impulse steam would be entering the indicator both at C and at D, and exhaust steam at A and at B. The valves I and E would now move downwards, uncovering their top ports. The impulse-steam valve I thereby opened communication at C between the steam side of the piston and the impulse pressure-gauge; but at D, the port being shut, no steam from this side of the piston could influence the exhaust pressure-gauge. Meanwhile the steam from the exhaust side of the piston entered the indicator at A and B. At A the port was open, making direct communication between the exhaust side of the piston and the exhaust pressure-gauge; but at B the port was closed, and there was no communication with the impulse pressure-gauge. On the return stroke the impulse steam and the exhaust steam again communicated directly with their respective pressure-gauges. The valve ports remained open or closed during the whole period of each single stroke of the engine piston. The piston valves were without lap; they might be worked either by a lever connected with an eccentric set 90° ahead of the engine crank, or by an equivalent motion, which could easily be obtained without an eccentric in an engine having the main cranks at right angles. The indicator might be made to work continuously, inasmuch as the wear and tear due to the movement of the working parts was extremely small; if required, it might be made to record a continuous mean-pressure line upon a continuously rotating drum.

Having checked this instrument against the ordinary indicator, he had found that with comparatively slow running engines it agreed within three or four per cent.; while the higher the speed went up, the greater became the accuracy. The average pressure indicated by the pressure-gauge was of course a time pressure average, whereas the average pressure registered by an ordinary indicator diagram was a space pressure average. If any ordinary indicator diagram were converted, as could easily be done, from a space diagram into a time diagram, it would be found that the error in the pressure-gauge method was extremely small. In his own experience he had found the instrument very useful.

Mr. M. HOLROYD SMITH gathered from the remarks of previous speakers that a great deal of trouble had been taken in so preparing the foundation on which an engine should stand that the vibrations caused by the engine should not be communicated to the most sensitive residents in the neighbourhood. It seemed to him however that the proper course would be to try to prevent vibration in the engine itself. This had no doubt been done to a large extent successfully; and yet in connection with motor-car work that he

(Mr. M. Holroyd Smith.)

had recently had in hand the question of vibration had again come prominently to the front. It therefore became necessary to go thoroughly into the subject of vibration in the engine itself. If he rightly understood the three classes of vibration mentioned in the paper, he agreed with them, though he thought they might be put somewhat more simply. In a vertical engine vibration might be taken as the result of the reciprocation of the piston up and down, and of the conversion of this reciprocating movement into a circular movement. The latter might be regarded as a combination of two movements at right angles, vertical and horizontal; and the difficulty of overcoming vibration resulted from the fact that, when the crank or disc of the engine was loaded with a balance weight and was revolving at approximately a uniform velocity, at the moment when the piston arrived at either end of its stroke the balance weight upon the crank was still moving at the same velocity, but in a direction at right angles to the movement of the piston. Therefore the balance weight which had been put upon the crank in order to balance the vertical downward movement of the piston was now producing an unbalanced horizontal movement of its own, when it swung across the vertical centre line at the top of its revolution, and again when it swung across at the bottom. The plan of arranging two or three or four cranks, or as many more as might be desired, did to a certain degree lessen this result; but it was still there all the same. Remembering that equal and opposite forces counterbalanced each other, he had reflected that the proper plan of balancing these movements would be to make two equal cranks, and cause them to revolve in opposite directions; and instead of putting the whole of the balance weight upon one crank, to divide it equally between the two. By this arrangement, with the cranks running opposite ways to each other, when the piston was coming down the balance weights were coming up on either side; and when the piston was stationary at the bottom or top of its stroke, the weights were crossing each other at the top or bottom of their revolution. This seemed sound reasoning, and the only difficulty still attending it in practice would be that, as the two weights crossing each other at the top and bottom of their revolution would not be crossing exactly in the same vertical plane, they would have a tendency to produce a slight oscillating movement of the crank-shaft longitudinally. The small model exhibited had been constructed in order to test the truth of this theory as thoroughly as it could be tested: more thoroughly indeed than it could be tested in the engine itself. As represented in the photographs, Plate 77, there was no cylinder surrounding the piston, and no bed-plate; there was simply a light frame-work for guiding the piston in its vertical movement, and for keeping the bearings together. The small fly-wheels here adopted were more ornamental than useful, because a fly-wheel of such lightness would not be fit for a piston of the proportionate weight here employed. The first thing illustrated by the working of the model was the well known effect of attempting to put a single-acting engine to work before putting any balance weights on it at all. It was seen that the vertical vibrations were then so violent even at a low speed as to cause the entire model to jump bodily up and down upon the table supporting it. The next step was to put the balance weights on in the ordinary way, for balancing as nearly as possible the weight of the piston; but as the balance weights revolved together in the same direction, according to the usual plan of balancing with a single weight, it was seen that, while the vertical jumping had been done away with, there was now a horizontal transverse oscillation to and fro, sufficiently powerful to produce both a visible and an audible side-shake, which not only communicated itself to the table supporting the model, but also produced a perceptible tremor in the platform on which the table stood. This experiment showed why success had not hitherto been attained in thoroughly balancing the weight of the piston: namely because of the evil effect of the violent side-shake which ensued from the unbalanced horizontal movement of the balance weight itself. As soon however as the ordinary single crank was divided into two, and the two balance weights which here replaced the ordinary single weight were compelled to revolve in opposite directions, it was seen that there was scarcely any shake in working the model, even at a high speed. The little that still remained was due simply to the necessity of working the model by gearing, which drove one of the

(Mr. M. Holroyd Smith.)

cranks; this crank had to act as a driver to the piston through the connecting-rod, which was alternately under compression and tension; the other crank was driven from the piston through the other connecting-rod, which was also under compression and tension, but in the reverse order; hence there was a slight knock as the two cranks passed the top and bottom centres in opposite directions. This would not occur in practice. As it was essential that the two cranks with their balance weights should invariably rotate in opposite directions, it was necessary to provide some arrangement which should preclude the possibility of their ever revolving in the same direction, from whatever position the engine might have to be started, or whichever way it might have to run. This object could be accomplished in many ways, one of which was illustrated in the diagrams, Plate 78; though not quite according to working proportions, they served to show the action clearly. Here each connecting-rod C was shaped like a bell-crank lever at its upper end, from which a link L was carried down to a sleeve S sliding upon a central vertical guide-pin I. With this contrivance it was evident that the two cranks could not possibly rotate in the same direction, and that their contrary rotation was thereby rendered compulsory.

Mr. LESLIE S. ROBINSON had recently had an opportunity of seeing a low-speed engine running on a method of lubrication somewhat similar to that described in the paper. In the last two boats that had been put on the Dover and Calais route by Messrs. Denny of Dumbarton a plan of forced lubrication was used, with the practical result that the trouble of wiping the engines down had been greatly reduced, and, as pointed out by the author, the attention necessary for such engines was also much reduced. The engines ran on the trips between Dover and Calais at a high speed of boat, and there had been no trouble with the lubrication; it was an entire success. Instead of oil a kind of grease was used, which was forced through at a pressure by a piston in a cylinder; and the rate of the lubrication depended upon the speed of the engine, just as it did in the self-lubricating engines described in the paper.

Mr. G. L. ADDENBROOKE said electrical engineers were all particularly interested in the speed at which an engine could be run. As electricity had now been adapted to so many other purposes besides lighting, it was important that the machinery employed in its generation should be as cheap as it could be made. The cost of dynamos varied largely with the speed at which they could be run; and if they could be run safely at a higher speed the capital cost of performing the work required would thereby be reduced. The advantage of high-speed engines was that they enabled the dynamos to be coupled direct to them; and this was the cause of the great success they had attained in electric lighting. The torpedo-boat engines in Table 1 he noticed ran at about 400 revolutions per minute and indicated about 2,250 horse-power; while the electric-lighting engines in Table 4 were about one-tenth of that size, indicating 217 horse-power and running at about 365 revolutions per minute, which was about the present usual practice for electric lighting. Hitherto engines of about 2,000 horse-power intended for electric work, particularly for driving tramway generators, had all been made slow-speed, especially in America. If in a torpedo-boat, where it had no foundations, an engine of that power and lightly built could be kept running at 400 revolutions per minute, he hoped there was a reasonable chance of making such an engine work continuously in a central electric station, where any amount of material could be put into it, and it could be worked under the best conditions. For indicating high-speed engines, he wondered that more use had not been made of the indicator worked out some years ago by Professor Perry,* on the principle of a diaphragm bulged by the steam pressure behind it and carrying a small mirror in front, which reflected a beam of light through an angle proportional to the deflection of the diaphragm, and could thus be made to give a permanent record photographically. As the instrument was one that could be mounted conveniently, and as its records could be taken easily, it appeared to him that there would be a great advantage in using it where engines were tested. It also had the further advantage that with high-speed engines the diagram assumed the appearance of a luminous line: so

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* Proceedings 1894, page 228 and Plate 53.

(Mr. G. L. Addenbrooke.)

that, without the trouble of taking diagrams in the usual way, it could be seen at the time what the engine was doing throughout the whole of the test. Having himself had to do with several Belliss engines, he had put them to severe tests. Three or four that he had tested eighteen months ago had been loaded up to the full extent, and the whole load then suddenly thrown off; and the rapidity with which they came back to their normal speed struck him as being exceedingly satisfactory. At the moment of the load being thrown off, the speed rose about 20 per cent. above the normal, and then came down again so quickly that in about four seconds the engine was running within 2 or 3 per cent. of its normal speed.

Mr. E. **Fuhrmann Clarke** noticed that the force pump supplying the oil under pressure for lubrication was a single-acting pump ; and he asked whether any observations had been made as to the variation in the pressure of the oil during a revolution of the engine. As the pump worked synchronously with the engine, he should suppose that the pressure would vary, unless there was some means of keeping the oil at a constant pressure. He should also like to know what pressure the oil was under when the engine was at work.

Mr. **Morcom** said there was always a certain amount of air in the oil, which tended to keep the pressure constant (page 354). On watching the small oil-pressure gauge fixed in front of any of the self-lubricating engines, it would be found that while running the finger of the gauge was kept steadily at the usual working pressure of about 15 lbs. per square inch. The single action of the pump therefore did not practically affect the steadiness of the pressure.

A big engine, of the size that would satisfy Mr. Addenbrooke's hope (page 353), he had no doubt could be built and made to run at any required number of revolutions within reason. Practically there was no reason why engines should not be run at much quicker revolutions than they were run at, especially the three-crank equal-angle. The main reason at present was that consulting engineers would not permit it. The evidence in favour of quick-revolving engines was growing slowly, and indications of progress could be seen in the manner in which the engine makers were pushing their way towards higher speeds of revolution. What was to be the limit he did not know. Already 400 revolutions per minute had been reached in the torpedo-boat destroyer machinery with 18 inches stroke, bringing the piston speed up to 1,200 feet per minute. Although the engine was not required to run for twelve months without stopping, he thought there would be no difficulty in running at 400 revolutions per minute for any period required in practice without stopping, if the parts were adequate for the work and the lubrication perfect.

The experience reported by Mr. Robinson (page 352) formed a practical confirmation of the beneficial action of forced lubrication on a large scale. There could be no doubt that, if the forced lubrication was tested on the bigger engines, the reduction of friction which had been shown in the diagrams exhibited from the smaller engines was bound to be felt to an equally important extent in the bigger.

The speech of Mr. Holroyd Smith (page 349) constituted of itself a paper in brief; and the exhibition of his model was most interesting. The vibration which had caused the annoyance referred to by Sir Edward Carbutt (page 337) had been due he believed to one of the Belliss engines in the St. James' electric station. It was a 300 H.P. engine, in which the couples or pairs mentioned in the paper had been got rid of entirely, and there was nothing whatever tending to make the engine itself rock or vibrate. Nevertheless it had been found necessary to take the engine out of the station: it was no use arguing from theory while in practice an annoyance was established. The obliquity of the connecting-rod he had not anticipated could be the cause of such trouble; but there was the fact, that the whole of the trouble in this case was due to it. A severe experience of a similar kind had at first befallen Mr. Crompton with an engine that had been put underneath the house in which he lived and slept. The engine was built in the same manner as that in the St. James' station. Afterwards a return connecting-rod was fitted in lieu of the direct one to the central or high-pressure cylinder, and this acted somewhat

(Mr. Morcom.)

in the same manner as Mr. Holroyd Smith's arrangement. As the pistons worked vertically upwards and downwards, the differences in the upward and downward retardation and acceleration which occurred in each stroke, due to the obliquity of the connecting-rod, caused a vertical vibration; but as soon as the return connecting-rod was put to work in the opposite direction, the two outer lines of working parts were counteracted by the central or high-pressure line, and the engine was most perfectly balanced, with the result he believed that the vibration had been reduced practically to zero. No doubt there were innumerable ways in which theoretically vibration could be brought to nought; but engines had to be made practically at a reasonable cost, and in competition with other makers. In engines with three cranks at equal angles the vibrations which had previously given trouble had been largely got rid of. With the two-crank engines Messrs. Willans had experienced considerable trouble in central stations; but with the three-crank engines the trouble had disappeared. The three-crank engine had moreover acquired a recognised commercial character; it was an engine that would sell, while a theoretically perfect engine would not sell, although in the paper he had himself been arguing in favour of the latter. The three-crank engine was practically good enough.

Before leaving the works this morning he had enquired how the preliminary testing had been proceeding of the engines for the City and Waterloo Railway which had just been completed for Professor Kennedy's final testing. In Mr. Addenbrooke's trials (page 354) he had spoken about the engine running up to 20 per cent. above the normal revolutions at the moment of the full load being thrown off; that was a point which had been passed long ago. For electric traction many engineers he believed would have gone in for engines with expansion-valve governors; but he had preferred not to do so after the experience he had had, and he had advised throttle governors. The result of this morning's testing he had heard was that the momentary variation from the mean steady speed was only 2·6 per cent. when the load was thrown off, and in a few seconds it settled down to 1·4 per cent. as the permanent increase above the

TABLE 7.—*Belliss 300 H.P. Quick-Revolution Self-Lubricating Engine fitted with Throttle-Valve Governor, for Waterloo and City Electric Railway.*

Results of Governor Tests after final adjustments.

Variation in Speed above and below general mean speed, load being switched off or on as suddenly as possible.*

Change of Load.	NON-CONDENSING.					CONDENSING.				
	Revolutions per minute.*			Percentage of Variation in Speed.		Revolutions per minute.*			Percentage of Variation in Speed.	
	From	To	Settle	Momentary.	Permanent.	From	To	Settle	Momentary.	Permanent.
	Revs.	Revs.	Revs.	Per cent.	Per cent.	Revs.	Revs.	Revs.	Per cent.	Per cent.
None to Half . . .	387	381	382	0·91	0·65	387	380	382	0·78	0·26
Half to None . . .	382	389	387	1·17	0·65	382	388	387	1·30	1·04
Full to None . . .	382	390	387	1·43	0·65	379½	392½	387	2·48	1·04
None to Full . . .	387	379	382	1·43	0·65	387	377	379	1·56	1·04
1–15th to Half . .	386½	382	382½	0·65	0·52	385	381	381	0·52	0·52
Half to 1–15th . .	382½	386½	386½	0·52	0·52	381	386½	385	0·91	0·52
1–15th to Full . . .	386½	377½	382½	1·82	0·52	385	375	379	2·09	1·04
Full to 1–15th . . .	382½	389	386½	1·17	0·52	379	389	386	1·56	0·78
Half to Full . . .	382½	379	382	1·43	0·65	381	377	379½	1·56	0·91
Full to Half . . .	382	384	383	0·13	0·39	379½	382	382	0·26	0·26
Emergency to None . .						379½	392½	387	2·48	1·04

* Steady Speed { Non-condensing, Full load 382 No load 387 Mean 384½ } revolutions per minute.
{ Condensing, „ „ 379½ „ „ 387 „ 383 }

(Mr. Morcom.)

mean speed. This was well within the contract, and fulfilled all the requirements of the engines for lighting the tunnels and carriages off the same current that supplied the motive power for the trains. [See Table 7, page 357.]

In enumerating in the paper the three classes of vibration, he had thought it undesirable to go further into the mathematical details (page 346), because in papers read to the Institution of Naval Architects the bugbear of vibration had been dealt with for many years; and it would there be found that almost every way in which vibration had been creating disturbance either afloat or ashore had been considered and he hoped remedied.

High-speed engineers, among whom Mr. Sisson was an authority, he was glad to find were not now disputing among themselves to the same extent that they were some years ago. They had a big battle to fight in common against the slow-speed engineers; and it was an encouragement when those who were best qualified by experience entered into the contest, and joined in pressing forwards in the direction in which they wanted to advance. An expansion-valve governor, if it could be arranged outside the engine and be made big enough and have room enough to work comfortably, he quite agreed with Mr. Sisson (page 345) was a first-rate governor, and acted exceedingly well. But in these high-speed self-lubricating engines it had been found that the governor had to be put inside, so as to get the benefit of the lubrication; and a governor inside was a great nuisance. Hence it had been a welcome discovery when it had further been found out that, owing to the more horizontal nature of the water-consumption curve obtained with forced lubrication, there would not be any considerable benefit in governing by the slide-valve rather than by the throttle-valve. No doubt economy was to be obtained, not only theoretically but practically, with the expansion-valve governor, where an engine had to be worked for most of its time at and under half load. All that he wished to point out was that the experiments recorded in the paper had been made carefully in order to show what amount of benefit in economy was being derived with the forced lubrication from expansion-valve governing as compared with throttling. The results showed clearly that with engines intended for working an electric-lighting station, that is to say, where the maximum economy was required to be at about three-quarters of the full load, it was not worth while to go in for the expansion-valve governor with a view to getting any saving at the year's end.

With reference to the oil pressure (page 344), the pressures that came upon the bearing were of course far higher than any oil pressure which he thought need be employed; but the pressure of oil was sufficient to establish a thick film flooding the whole bearing surface, when the action of the return stroke parted the surfaces slightly. All engineers who had used these self-lubricating engines would agree that, when the lubricant and fitting were correct, this film prevented contact, because the oil could not be squeezed out in the very small fraction of a second taken up by a single stroke. The film of oil should be able to do its work so effectually during the acting stroke that the particular metal used for the bearing ought not to be of much importance. If the wear were taking place on the oil itself and not on the metal, it did not matter whether white-metal or gun-metal was used. But as the difference in cost between white-metal and gun-metal bearings for steel journals was inconsiderable, caution had led him always to put the white-metal bearings in where the journals were of mild steel, for fear of any possible mishap with harder bearings. With the oil pressure however, a harder metal he thought could be adopted for the bearings, if necessary; but he did not contemplate making the trial himself.

The quantity of oil used with the forced lubrication was much less than that required with the ordinary mode of lubrication (page 342). Into one of the engines driving the works of Messrs. Belliss about 10 gallons of oil were put, and at the end of six weeks there was found to be about 12 gallons. The reason appeared to be that there was some water coming from the glands, which presumably got so intimately mixed with the oil as to increase the volume to that extent.

The question of clearance, which had been brought up by Mr. Saxon (page 341), was an old bugbear. In these quick-rotating engines with single-eccentric valve-gear he should not

(Mr. Morcom.)

be surprised if it was as much as a quarter of the stroke; certainly it was something more than an eighth. In the Cheltenham engine (page 327) the actual clearance was 22 per cent. in the high-pressure cylinder and 15 per cent. in the low-pressure. But even when varying it between large limits he had found that it had hardly any effect, if the necessary care was taken with the slide-valves to ensure that the compression was right for enabling the proper indicator curves to be obtained. Anyhow the good results recorded in the paper were those which had been arrived at with the clearances as they actually existed. If there was anything to be gained by reducing the clearance, of course this could be done. In the engines illustrated in the drawings there were great advantages in having the slide-valves placed where they would readily be seen and got at by engineers who liked to have as few working parts as possible. From his own experience he was willing to accept the clearance, however great; for he had found no difficulty from it as far as economy was concerned, when required to guarantee as great an economy of water per horse-power as was possible with any other engines. He had not found that a modification of the clearance necessarily affected the economical working of the engines to anything like the extent that many engineers evidently believed.

The reason why governing by the throttle valve was better when the electric horse-power was made the basis for measuring the water consumption (page 335) was that the expansion-valve governor in itself caused losses by friction and otherwise, whereby the efficiency of the engine was reduced. Hence the results per effective horse-power, and therefore per electric horse-power, came out worse with the expansion-valve governor than with throttle-valve governing.

The inexpediency pointed out by Mr. Donkin (page 334) of calling these engines "high-speed" engines had already been realised by the makers, by whom they were now called "quick-revolution" engines. The latter designation had been substituted for some time past, and it was undoubtedly the right one to use.

With the modification suggested by Professor Unwin (page 334) in regard to Table 5 he entirely concurred; and the revolutions of the engines selected as examples had accordingly been added to the table. Having himself received his engineering education from Professor Unwin thirty years ago, he thought that probably the seed which had then been sown in his mind might have been germinating gradually towards self-lubrication; and he wished that the fatherly interest which Professor Unwin might therefore be expected to take in the subject had tempted him to amplify his remarks thereon.

The important suggestion offered by Mr. Thornycroft (page 333) had already led to a considerable modification of the arrangements, for enlarging the settlement space provided in the base of the engine, so as to permit the oil to get free from dirt. In the latest engines the oil was carried away through pipes into a well space, where it could have a sufficient period of quietness for the dirt to settle. At the central station in Birmingham it was carried away to a small tank outside the engine, where it had a still longer period of quietness. At Leeds, and at the Charing Cross and Strand Electric Supply, and at many other stations, the same plan was now carried out; the oil was led right away from the engine into a settling tank.

The question about a reasonable factor of safety (page 334) was such a poser that he was half inclined to regard it as having been asked sarcastically. At any rate an attempt to reply thereto would involve a much longer paper than the present, and even then he feared would probably fail to meet the requirements of engine builders generally.

The **President** was sure Mr. Morcom must have been highly gratified by the animated tone of the discussion, and by the cordial acknowledgments expressed by those who had spoken on the subject of the paper. He himself thoroughly endorsed all that had been said as to the value of the paper; and he invited the members to show their appreciation by a hearty vote of thanks to the author.

Mr. **W. W. F. Pullen** wrote that he presumed the small single-crank engines referred to in page 321 were all fitted with piston-valves. If so, he asked whether they were plain piston-valves without rings,

(Mr. W. W. F. Pullen.)

and how much smaller in diameter was the valve than its seating; and whether these valves had been tested for leakage, both standing and running, and with what result. In some trials which he had recently made of a small non-compound double-acting engine, fitted with a plain piston-valve without packing of any kind, he had found the leakage past the valve was excessive; the normal speed was 350 revolutions per minute. This he believed was not an isolated example. If leakage to any great extent did take place past a piston-valve, the reason for employing a piston-valve was done away with, and it would be more economical to revert to the old **D** slide-valve with a plane face.

Details of the gland packing used in the engines which gave so remarkable a mechanical efficiency would be acceptable; because it was well known that ordinary packing might be so screwed up as to put a considerable load on the engine, whereas this was impossible with many of the metallic packings now used.

In the trials recorded in Table 4, page 326, he noticed that at all loads the engine was more efficient as a machine than the dynamo which it drove. According to the figures here given, the efficiency of the dynamo could not be much above 94 per cent. at normal full load, and 90 per cent. at half load; whereas the corresponding efficiencies of the engine were seen to be 96 and 94 per cent. respectively.

The advantages of forced lubrication, which would generally be admitted by those who had had experience of it in the Belliss engines, were emphasized by the trials here recorded. But in the face of the journal experiments of Mr. Dewrance (Proceedings Inst. C.E., 1896, vol. cxxv, page 351) he thought the assertion in page 324 was hardly justified, that in a single-acting engine under constant thrust no such film of oil was possible as was maintained between the bearing surfaces of a double-acting engine by forced lubrication. In a constant-thrust splashed bearing, the film of oil of course could not be so thick as with forced lubrication. The question was to a great extent one of thickness of the oil film. In a set of Belliss engines under his own charge he had found that a thin oil with little body would allow knocking to take place, while a little thicker oil would completely eliminate all traces of knock. With impure mineral oil, in which the leakage of water from the glands produced saponification, the engines ran smoothly, but the oil pressure rose to 20 and 25 lbs. per square inch. It would be interesting to learn what effect was produced upon the running of the self-lubricating engine by considerably increasing the oil pressure, and what limiting pressure the oil connections would stand. In the engines of which he had charge the little oil safety-valve at one time made so much noise that it was impossible by the ear to form any opinion as to how the engines were running; and an india-rubber buffer had to be inserted for preventing the noise.

With these engines he had experienced no trouble from vibration. They were of the two-crank kind with the cranks opposite, running at 450 revolutions per minute. The foundation was deep, and completely isolated from the surrounding floor and other foundations. The exhaust pipe, which was heavy, vibrated a little, and communicated the vibration to the feed heater, but with no ill effect. Were it necessary to avoid the vibration of steam or exhaust pipes, the connections might be made with flexible metallic tubing.

In the trials mentioned in page 325 he should like to know the kind of brake used, and how it was applied to the engine tested.

Mr. Morcom replied that the small single-crank engines were all fitted with solid piston-valves, and in grinding these valves into the bores in the cylinder casting great care was taken to ensure the absolute accuracy of the guide with the bore. With proper care in this matter it was found that the wear on the valve was so trivial that experiments made on one of the small engines at their works after eighteen months' constant running showed no difference in the economy. With a high-speed engine the escape of steam when the valve was running was naturally much less than it would be with the valve standing under the same steam pressure.

The engines were generally completed with metallic packing for the high-pressure piston-rod, and soft packing for the low-pressure rod; but on the trials the glands were packed with asbestos dagger packing for the high-pressure, and locomotive packing for the low.

(Mr. Morcom.)

Care was of course taken to avoid screwing up this packing any harder than was necessary for securing steam and vacuum tightness.

Mr. Pullen's experience with the thick oil and thin oil appeared to prove the assertion made in the paper as to the difference between the film of oil with forced and ordinary lubrication. With a sufficiently thick oil, as that experience showed, more time was required to drive out the lubricant from between the surfaces than the speed of the engine permitted, and this would also occur with a thinner oil if the surfaces were closer fitting; but without such a thickness of film the surfaces would probably be permitted to come into contact, entailing an increase of friction and wear. The experience gained by his firm seemed to prove this clearly.

The trials mentioned in page 325 had been made with a Froude water-brake coupled direct to the engine shaft.

EXCURSIONS.*

On Tuesday Afternoon, 27th July, after luncheon in the Grand Hotel, visits were made to the following Works, which were also open on Wednesday afternoon and on Thursday and Friday. Descriptions of most of these are given in pages 370–404.

Messrs. Belliss and Co., Engine Works, Ledsam Street.
Birmingham Electric Supply Station, 14 Dale End.
Birmingham Small Arms and Metal Works, Gun Department, Small Heath.
Botanical Gardens, Westbourne Road, Edgbaston.
Corporation Central Fire Station, Upper Priory.
Corporation Gas Works, Windsor Street; and Saltley.
Corporation Hydraulic Power Supply Station, Dalton Street.
Corporation Interception Wharf, Montague Street.
Corporation Water Works.
Messrs. Elkington and Co., Electroplating Works, Newhall Street.
New General Hospital, Steelhouse Lane.
Messrs. Joseph Gillott and Sons, Steel Pen Manufactory, Graham Street.
Messrs. John Hardman and Co., Stained Glass Works, 43–44 Newhall Hill.
Messrs. Hardman, Powell and Co., Metal Works, King Edward's Road.
Messrs. J. H. Hopkins and Sons, Tinplate Works, 68 to 82 Granville Street.
Lloyd's Proving House, Netherton, Dudley.
Mason University College, Edmund Street.
Messrs. McCallum and Hodson, Papier Maché Works, 66 and 68 Summer Row.
Mirror Laundry, Park Hill Road, Harborne.
Messrs. Henry Mitchell and Co., Cape Hill Brewery, Smethwick.
Municipal Technical School, Suffolk Street.
National Telephone Co., Switchroom, 40 Bennett's Hill.
Messrs. F. and C. Osler, Glass Works, 230 Broad Street; and Freeth Street.
Osmond Cycle Works, The Tower, Bagot Street.
Gun Proof House, Banbury Street.
Sandwell Park Colliery, West Bromwich.
Messrs. P. Webley and Son, Gun Manufactory, 86–89 Weaman Street.
Messrs. Winfields, Cambridge Street Works and Rolling Mills.

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* The notices here given of the various Works &c. visited in connection with the Meeting were kindly supplied for the information of the Members by the respective proprietors or authorities.

In the evening the Institution Dinner was held in the Grand Hotel, and was largely attended by the Members and their friends. The President occupied the chair; and the following Guests accepted the invitations sent to them, though those marked with an asterisk * were unavoidably prevented at the last from being present.

The Right Honourable the Lord Mayor, Councillor James Smith; the Worshipful the Mayor of Wolverhampton, Alderman Stephen Craddock *; the Deputy Mayor of Coventry, Alderman J. B. Loudon; Mr. Ebenezer Parkes, M.P.*; Professor W. Cawthorne Unwin, F.R.S., Honorary Member; Mr. Richard Williams, Original Member.

Executive Committee.—Mr. Arthur Keen, *Chairman*; Mr. W. Bayley Marshall and Mr. Eric M. Carter, *Honorary Secretaries.* Mr. Thomas R. Bayliss *; Mr. Reuben Farley; Mr. W. H. Greenwood; Mr. T. Bernard Hall; Mr. Henry Lea; Mr. S. Zachary Lloyd; Mr. Edward B. Marten; Mr. Alfred Morcom; Mr. George H. Morley *; Mr. John C. Vaudrey; Mr. Thomas F. Walker.

Authors of Papers.—Mr. Henry Davey; Mr. Philip Dawson *; Mr. John Jameson; Mr. Alfred Morcom; Mr. F. J. Osmond.*

Councillor C. G. Beale, Acting Chairman of the Water Committee; Councillor R. F. Martineau, Chairman, Technical School Committee; Dr. R. S. Heath, Principal, Mason University College; Dr. W. E. Sumpner, Principal, Municipal Technical School; Mr. P. A. Forbes; Mr. Alfred Herbert; Mr. W. H. Waister.

Mr. Edward P. Martin,* President of the Iron and Steel Institute; Mr. R. S. Williamson,* President of the South Staffordshire and East Worcestershire Institute of Mining Engineers; Mr. Job Cox, President of the Birmingham Association of Engineers; Mr. John Duckitt, Secretary of the North-East Coast Institution of Engineers and Shipbuilders; Mr. Alexander Smith,* Secretary of the South Staffordshire and East Worcestershire Institute of Mining Engineers; Mr. Angus Macpherson, Secretary of the Cleveland Institution of Engineers; Mr. L. O'Brien, Secretary of the Birmingham Association of Engineers. Mr. A. Entwistle, District Superintendent of the London and North Western Railway;

Mr. E. Antony Lees, Secretary of the Birmingham Corporation Water Works; Mr. Edward Murphy,* Divisional Superintendent of the Great Western Railway.

The President was supported by the following officers of the Institution: — *Past-Presidents,* Sir William Anderson,* K.C.B., D.C.L., F.R.S., Sir Edward H. Carbutt, Bart., Mr. Charles Cochrane, and Mr. Jeremiah Head; *Vice-Presidents,* Sir Douglas Galton,* K.C.B., D.C.L., F.R.S., Mr. Samuel W. Johnson, Mr. Edward P. Martin*, Mr. William H. Maw, and Mr. J. Hartley Wicksteed; *Members of Council,* Mr. Henry Davey, Mr. Bryan Donkin, Mr. Arthur Keen, Mr. John I. Thornycroft, F.R.S., and Mr. A. Tannett Walker.

After the usual loyal toasts, the President proposed "The City and Trade of Birmingham," which was acknowledged by the Right Honourable the Lord Mayor, Councillor James Smith. The toast of "Technical Education," proposed by Mr. J. Hartley Wicksteed, Vice-President, was acknowledged by Councillor Martineau, Chairman of the Technical School Committee. Sir Edward H. Carbutt, Bart., Past-President, proposed the toast of "The Corporation Engineering Works," which was acknowledged by Councillor Beale, Acting Chairman of the Water Committee. The toast of "Neighbouring Municipalities," proposed by Mr. William H. Maw, Vice-President, was acknowledged by the Deputy Mayor of Coventry, Alderman J. B. Loudon. Mr. H. Graham Harris proposed the toast of "The General Committee and the Honorary Secretaries," which was acknowledged by Mr. Arthur Keen, Chairman, and by Mr. W. Bayley Marshall and Mr. Eric M. Carter, Honorary Secretaries. The final toast of "The President," was proposed by Mr. Richard Williams, Original Member of the Institution.

On WEDNESDAY AFTERNOON, 28th July, after luncheon in the Grand Hotel, three alternative Excursions were made. By special train to Wolverhampton, where the Members were received in the Town Hall by His Worship the Mayor, Alderman Stephen

Craddock. Thence by special brakes to visit the following works:—Great Western Railway Locomotive Works (page 405), under the guidance of Mr. W. H. Waister, Assistant Locomotive Superintendent; Electric Construction Engineering Works, Bushbury (page 405), under the guidance of Mr. A. B. Blackburn, Manager; Messrs. Thomas Parker, Electrical Engineering Works (page 407), under the guidance of Mr. Thomas Parker; and the Wolverhampton Corporation Electric Lighting and Power Station (page 408), under the guidance of Mr. F. Harman Lewis, Borough Electrical Engineer.

A second excursion was made to Oldbury, where the boiler works of Messrs. Edwin Danks and Co. (page 409) were visited, under the guidance of Mr. T. Bernard Hall, Director.

A third excursion was made to Dudley Port, where the Horseley Co.'s Bridge and Roofing Works were visited, under the guidance of the Directors, by whose kindness afternoon tea was provided at the Works.

In the evening the Members were invited by the Local Committee to a Conversazione in the Botanical Gardens, Edgbaston.

On Thursday, 29th July, two alternative Excursions were made.

One was by special train to Stratford-on-Avon, where the Members were received in the Town Hall by the Deputy Mayor, Alderman John Smallwood. Visits were then made, under the guidance of the Deputy Mayor and gentlemen of the local Shakespearian Society, to Shakespeare's Birthplace, the Shakespeare Memorial Buildings, Trinity Church, and the Guild Chapel; and by brakes to Charlecote Park, by permission of Mr. Fairfax Lucy, and to Anne Hathaway's Cottage, Shottery. Luncheon was provided in the Town Hall, kindly lent by the Mayor for the occasion.

Another excursion was made by special train to Walsall, where the Members were received in the Guildhall by His Worship the Mayor, William Smith, Esq. The following Works were visited under the guidance of the proprietors and managers:—Messrs. John Dewsbury and Son (page 411), Bridle-Bit Makers and Nickel

Platers; Messrs. E. T. Holden and Son (page 412), Tanners and Curriers, Japanners, Enamellers, and Leather Manufacturers; Messrs. John Leckie and Co. (page 413), Wholesale Saddlers and Harness Manufacturers; Messrs. John Russell and Co. (page 414), Alma Tube Works and Cyclops Iron Works; Messrs. John Shannon and Son (page 416), Wholesale Clothiers and Woollen Warehousemen; and Messrs. Stokes and Co., Tanners and Curriers. Brakes were provided by the kindness of Messrs. John Russell and Co. for visiting their Tube Mills and Iron Works.

On FRIDAY, 30th July, an Excursion was made to Coventry, where the Members were received in St. Mary's Hall by the Deputy Mayor, Alderman J. B. Loudon. The following Works were visited under the guidance of the proprietors and managers:—Daimler Motor Mills (page 419); Messrs. Alfred Herbert's Machine-Tool Works (page 421); Triumph Cycle Works (page 423); Messrs. Bayliss, Thomas and Co.'s Cycle Works; Messrs. Humber and Co.'s Cycle Works (page 424); New Premier Cycle Works (page 427); Messrs. New, Townend Brothers' Cycle Works; Messrs. Joshua Perkins and Sons, Britannia Weaving Mill (page 428). After luncheon by invitation of Mr. Alfred Herbert at his works, one party proceeded by special train to Warwick to visit the Castle, by permission of the Earl and Countess of Warwick, or Guy's Cliff, by permission of Lord Algernon Percy. Another party proceeded by special train to Rugby, to visit the Victoria Works of Messrs. Willans and Robinson (page 429), by whose kindness afternoon tea was provided at their works.

A memento of the Jubilee of the Institution was presented by the Local Committee to each Member attending the meeting, in the form of a Medal bearing on the obverse the head of George Stephenson, the first President of the Institution, and on the reverse the Arms of the City of Birmingham.

MUNICIPAL TECHNICAL SCHOOL, SUFFOLK STREET, BIRMINGHAM.

The Birmingham Technical School is one of the largest and best equipped of the schools which have been erected in various parts of the country for carrying on the work of technical education. The land, building, and equipment cost over £88,000, for which the sinking fund is taken from the excise duties voted by parliament for this purpose; for Birmingham these duties provide an income of about £10,000 a year.

The work of the school is entirely confined to science and its applications. The number of students in attendance last session exceeded 2,500, of whom 677 took workshop courses. Large and well-appointed workshops are provided for brass-founding, iron and steel work, plumbing, carpentry and joinery, pattern making, sheet metal work, electrical instrument making, and electrical jointing. The mechanical drawing classes are remarkably large; over 800 students take the subjects of practical geometry, building construction, and machine drawing. The chemical, metallurgical, and electrical departments are also well attended.

Hitherto the work of the school has been confined to evening classes; but a day science school is being opened this autumn for boys from twelve to sixteen years of age. The school fee is only £3 a year.

CORPORATION GAS WORKS, WINDSOR STREET, BIRMINGHAM.

These gas works adjoin the Birmingham Canal, and have also a connection with the London and North Western Railway. They are mostly modern, and occupy an area of about 26 acres; the present productive capacity is about 10½ million cubic feet of coal gas a day, which is capable of being considerably increased by the complete utilization of the site. There is also a carburetted water-gas plant, which, when the extensions now in progress are completed, will have a productive capacity of 4 million cubic feet a day. The gasholders are eight in number, having an aggregate capacity of about 16½ million cubic feet.

The principal retort house is 487 feet long by 210 feet wide, covering an area of about 2⅓ acres. It is served by three overhead lines of railway, by which the coal is delivered without break from the colliery. There is also on the lower or yard level a canal arm, which extends to more than three-fourths of the length of the house. The retorts numbering 740 are of D shape, 22 inches by 16 inches, and 21 inches by 15 inches, and are set in beds of eight and nine. The beds are arranged in two parallel rows, having the canal arm between them, and the railway on both sides of each row, 20 feet above the yard level, and 10 feet above the retort charging-floor. The retorts are all heated by regenerative furnaces, on Hunt's plan. Foulis-Arrol hydraulic machinery is used for charging and drawing them; and Ross drawing machines actuated by steam are also employed. The coal is for the most part received in steel hopper-wagons having sliding bottom-doors on Hunt and Shackleford's plan, which are discharged in a few minutes. After passing through a coal-breaker, it is elevated and distributed into overhead hoppers, from which the retort charging-machines are supplied. The distribution of the coal is effected by means of conveyors formed of cotton belting 21 inches wide, extending throughout the length of the house. During the winter about 800 tons of coal are thus dealt with daily. From some of the retorts the hot coke when drawn is removed by a conveyor placed on a level with the retort charging-floor, and immediately underneath the retort mouthpieces. It is quenched on its way out by water sprays placed at intervals along the conveyor; and by means of an elevator and another conveyor is carried across the yard to a hopper, from which it passes into a revolving screen. Here the dust is separated; and the coke, sorted into various sizes, falls upon picking belts, where bats &c. are removed, and thence falls into bags for loading into customers' carts or vans. A sunken roadway for the latter, whereby the necessity for lifting the bags is avoided, completes the arrangement by which, from the commencement to the end of the process, manual labour in carbonizing coal is almost entirely dispensed with.

The condensers are some of them of the battery kind, and others on the ordinary vertical plan. The exhausting machinery consists of two of Beale's rotary exhausters, having each a capacity of 150,000 cub. ft. per hour, made by Messrs. Waller and Co., each driven direct by a 16 × 20 ins. horizontal condensing engine; and one Donkin's improved Beale of 200,000 cub. ft. per hour, driven direct by a 14 × 20 ins. non-condensing Robey engine; and a pair of Beales, each of 150,000 cub. ft. per hour, coupled to a horizontal tandem engine made by Messrs. W. H. Allen and Co., with high-pressure cylinder 16 ins. diameter, low-pressure 25 ins. diameter and 18 ins. stroke. Steam is supplied for various purposes by ten Babcock and Wilcox boilers and three Lancashire boilers; the former are worked up to 120 lbs. pressure, and have forced draught for burning dust-fuel.

From the outlet of the condensers the gas passes through three Livesey washers; and from the outlet of the exhausters the ammonia is removed by two of Kirkham, Hulett, and Chandler's washer scrubbers, each having a capacity of 5 million cub. ft. a day, and by one of Mann and Walker's tower scrubbers 20 ft. diameter and 60 ft. high.

There are two sets of four purifiers, 66 ft. by 32 ft., and one set of six, 40 ft. by 32 ft., with overhead lime shed. Three station-meters, each passing 150,000 cub. ft. per hour, measure the gas on its way to the gasholders. Of the latter the two largest have each a capacity of 6¼ million cub. ft.; each has three 50 ft. lifts, the outer one being 236 ft. diameter, and including the rise of crown the total height is 165 ft. There is a Maxim-Clark carburetting apparatus, having a capacity equal to one million cubic feet of coal gas per hour, enriched to the extent of one sperm candle. The enriching material used is either benzene, or a light spirit having a specific gravity of about 0·68, according to which may be the cheaper at the time of purchasing. For this material there is an underground storage tank, capable of containing about 25,000 gallons.

Coal is stored under the viaduct approaches to the retort house, the rails on the viaduct being 20 feet above road level. As required for use in the retort house it is picked up and loaded into wagons by elevators, of which there are three, 41 feet high and placed in suitable positions.

The experimental works and laboratory comprise three cast-iron retorts in separate settings, each to carbonize half-cwt. charges; condensing and purifying apparatus, and three gasholders of 20 and 350 and 970 cubic feet capacity; also laboratory and photometrical appliances for general testing.

The carburetted water-gas apparatus is on the Merrifield-Westcott-Pearson plan, and comprises two sets of generators, superheaters and fixers, condensers and scrubbers; each set is capable of producing one million cubic feet of gas per day. There are also boilers, exhausters, air-blowers, pumps, tar separator, station meter, oil tank to contain 400,000 gallons, and a set of four purifiers, 40 ft. by 30 ft., having discharging floor underneath, and lime sheds on either side. The whole of this apparatus is in course of being duplicated. There is also a relief gasholder 78 feet diameter and 20 feet deep, which is rope-guided on the plan of Messrs. Ashmore, Benson and Pease.

Through the meter repairing shops pass annually from 8,000 to 9,000 meters. Upwards of 191,000 tons of coal were carbonized during 1896; and the total quantity of gas produced amounted to 1,907 million cubic feet. Mr. Charles Hunt is the engineer in charge of these gas works. The number of men employed is about 750.

CORPORATION GAS WORKS,
SALTLEY, BIRMINGHAM.

These gas works formed one of the three stations of the late Birmingham and Staffordshire Gas Co., whose undertaking was acquired with that of the Birmingham Co. by the Birmingham Corporation in 1875; and is now one of the two principal stations of the city gas department. At the date of the transfer the manufacturing capacity of these works was but 5¼ million cubic feet per day, and the storage 4½ million cubic feet. Since then important additions have been made, which have raised the daily make of coal gas to 10¼ million cubic feet, and the storage to 8½ million cubic feet; and work is now in progress for increasing the latter to 19 millions.

The coal-gas works occupy 18½ acres, and 32 acres adjoining are available for future extensions. On the Devon Street site, west of the Midland Railway, works for the manufacture of carburetted water-gas were erected last year, adapted for making 2¼ million cubic feet of gas per day; and the buildings were arranged for duplicating this make to 4½ million cubic feet per day. It was expected that the provision of last year would have sufficed for at least a couple of years; but owing to the abnormal demand for gas last winter, sometimes reaching over 20 per cent. beyond the preceding year, both the coal-gas and the water-gas plants at all the works were severely taxed, only a small margin of productive power being left available for the possible further increase of next winter. This extraordinary demand was no doubt to a great extent due to the large demand for gas for motive power and trade purposes generally, but particularly in connection with the cycle industry; and as it was practically impossible to increase the coal-gas plant in time to meet the requirements of next winter, it was decided to proceed at once with the duplication of the water-gas plant at Saltley and Windsor Street Works, which is now being done. The works are divided into two sections; the gas made in the old retort houses is in the subsequent stages dealt with generally in the new plant, while the old plant is utilized for that produced in the new retort house No. 3; provision however is made for the plant in either section to be worked separately or in conjunction.

Nos. 1 and 2 retort houses contain seven benches of retorts, seven in a setting, two of the benches being heated on the more modern regenerative plan, in which only one fire is required per setting: instead of two, one on either side, as in the old plan of ordinary fires. In the newer plan the primary air-supply is limited, so that the gas thus produced from the coke is principally carbonic oxide, which, on issuing from the furnace into the combustion chamber, meets with a regulated supply of secondary air, required for combustion, and heated previously by the waste furnace-gases; by this method the temperatures are more under control, and a large saving in fuel and labour is effected. In these old houses, the charging and drawing operations are still done by hand, because the houses are too narrow for the introduction of machinery.

No. 3 retort house is the most modern; it contains two benches of nineteen beds of retorts in settings of eights, one bench of nine beds in settings of sevens, and one bench of twelve beds of retorts in settings of sevens. The whole are heated on the regenerative plan already mentioned; and all the retorts are drawn and charged by West's machinery worked by compressed air. In this house most of the coke drawn from the retorts is caught on continuous conveyors, which empty upon a cross conveyor leading to a skip pit; it is quenched on the way thither, and falls into a skip made to contain about two tons of coke, which is raised by a large hydraulic crane, and either tipped upon a screen for loading trucks, or upon another for loading boats, or conveyed to stock, as may be required. The labour in dealing with both coal and coke is thus reduced to a minimum; in fact most of the coke dealt with entails no manual labour whatever. In the hydraulic crane, constructed by Sir W. G. Armstrong, Mitchell and Co., the bogie travels along the entire length of the jib of $74\frac{1}{3}$ feet radius, so that the coke from the skip can be tipped anywhere within the area covered by this radius. The lifting ram is $6\frac{1}{4}$ inches diameter and 21 ft. $10\frac{1}{2}$ ins. stroke, the slewing ram $8\frac{1}{2}$ inches and 5 ft. 11 ins., the traversing ram $2\frac{7}{8}$ inches and 10 ft. 10 ins., and the tipping ram $3\frac{3}{4}$ inches diameter and 3 ft. 5 ins. stroke.

On leaving the retort houses, the gas is drawn by the exhausters through large pipes above ground, wherein it is partially cooled, into the atmospheric condensers, some of which are vertical and others horizontal; the exit temperature, being under control by valves, ranges from 50° to 70° Fahr. From the condensers the gas passes to the washers and scrubbers, in which the remaining tar, ammonia, and some of the other impurities are extracted. From the exhausters, the gas is forced through the purifiers and station meters into the storage gasholders. The purifiers are filled principally with hydrated lime for eliminating carbonic acid, sulphuretted hydrogen, and other sulphur compounds. As a safe-guard, in connection with each section there are "catch" boxes filled with oxide of iron, to arrest any sulphuretted hydrogen which may accidentally escape the lime purifiers.

The carburetted water-gas apparatus is upon the Lowe type, embodying the designs of Merrifield, Westcott and Pearson, and was supplied and fixed by the Economical Gas Apparatus Construction Co. of Toronto and London; the buildings, roofs, purifiers, gasholder, and oil-storage tanks were erected under separate contracts from the engineer's designs. For making the water-gas, a layer of coke is put into the generator, and ignited; and the generator having then been filled up with coke, air is blown in at the bottom, which raises the mass to a glowing heat. The products of combustion passing into the superheater and fixing chamber heat the interior mass of firebrick work to the required temperature; air is simultaneously admitted into the superheater with the object of consuming any carbonic oxide that might otherwise escape unconsumed. After the coke and apparatus have in this way been raised to the required temperature, the air is shut off, and water-gas making commences; steam is injected at the bottom of the generator for an "up run" and at the top for a "down run," and coming in contact with the incandescent carbon is decomposed; hydrogen gas is given off, and the oxygen of the steam uniting with the carbon of the coke forms carbonic acid and carbonic oxide, some of the carbonic acid being subsequently converted into carbonic oxide in passing through a further mass of incandescent carbon. The gas thus produced is chiefly a mixture of hydrogen and carbonic oxide, but even with the best working there is a small percentage of carbonic acid. From the generator the mixture of gas passes to the superheater and carburetter, where it meets with heated oil, "Russian solar distillate"; the oil is previously heated in a separate part of the apparatus by the heat of the water-gas itself on its way to the condensers. The quantity of oil used depends upon the illuminating power required, which may vary from 17 to 30 candle-power or even through a wider range. The making of gas lasts from six to nine minutes; at the end of this time the steam is shut off, and the air blast renewed for several minutes, in order to raise the coke again to a sufficiently high temperature for decomposing the steam in the next run. The process is thus one of alternate blows and runs.

The total output of gas from these works in the year ending 31 March 1897 was more than 2,293 million cubic feet. Mr. Henry Hack is the engineer in charge of these works. The number of men employed is about 900.

CORPORATION INTERCEPTION WHARF, MONTAGUE STREET, BIRMINGHAM.

These works, situated in almost the centre of the city, were established in 1878 for the purpose of dealing with part of the daily collection of house refuse. The wharf has an area of 17,130 square yards. The main buildings have an area of 5,277 square yards, exclusive of stabling, which is here provided for 78 horses out of the total of 206 owned by the health department. During the year ending December 1896 the various kinds of refuse collected and disposed of amounted to 199,588 tons, of which about 80,000 tons were delivered to this wharf. In 1874 the "pan" system of collection was introduced into Birmingham, and it was subsequently found necessary to make some portion of the contents into concentrated manure. On arriving at the wharf the pans are emptied into tanks, and a small quantity of sulphuric acid is added in order to fix the ammonia, and to prevent the loss arising from its evaporation under the action of heat. From the receiving tanks the material is run into tanks immediately over the drying machines, and provision is made for charging the drying machines direct from these tanks. There are five steam drying machines and two hot-air drying machines. After being properly dried, the concentrated manure is ground in a mill, and is then ready to be packed in bags and sent away; it contains about 7 per cent. of ammonia and 7 per cent. of phosphates. Of the dry refuse, part is riddled in octagonal rotating screens, which separate the fine ash from the rougher material; the latter is further sorted by removing broken glass and crockery, brick ends, tin cans, &c. Rags are not picked out, but are burnt in the furnaces with other combustible matter. Part of the fine ash is mixed in a pug mill with the pan contents, and sold as manure; it is discharged into boats from the mixing machines. Thirty cells or furnaces are kept going for burning refuse, and on an average they get rid of 1,100 tons of refuse per week. The heat produced by its combustion is utilised for the generation of steam required in the manure manufacturing process, and for various other purposes; there are twelve multitubular boilers, and two Galloway boilers. The number of men employed at this wharf is 242; Mr. William Holt is the superintendent and engineer.

MESSRS. G. E. BELLISS AND CO., LEDSAM STREET WORKS, BIRMINGHAM.

These works were founded in 1870, when Mr. G. E. Belliss transferred his general engineering business from Broad Street to the present site. Some years previously the Admiralty had introduced steam launches into the naval service, and Mr. Belliss brought out a design of high-speed engine specially adapted for their propulsion, which was found so suitable that the works were soon almost exclusively employed in its production. Later on were added engines for torpedo boats, and auxiliary machinery for ships for our own and for foreign governments.

About eight years ago the manufacture of high-speed engines for driving dynamos direct was commenced; it has since developed into a most important branch of the business, and has involved large extensions, some of which are now in progress. Owing to the growth of the business, a separate foundry and pattern-making department was started adjoining the works, the entrance being at the junction of Ledsam Street with Great Tindal Street, where a large staff of men are employed in the production of iron castings and the patterns necessary for them. A new building in close proximity to the London and North Western Railway is also approaching completion for the electric-light department.

The main works comprise numerous machine shops, equipped with the most modern appliances for the production of interchangeable engine parts, brass foundry, brass finishing shop, coppersmiths' shop, erecting shops, drawing and account offices, stores, &c. The testing department is well furnished with all the most modern instruments for engine and dynamo testing, including a Froude water dynamometer, condensing apparatus for condensing the exhaust steam from engines on test, with tanks, and machines for weighing it. The resistance frames for absorbing the current generated in the dynamos on test are arranged round the walls and under the roof of the building. They are divided into sections, with switches for taking up various amounts of current, and when used to their utmost capacity are capable of absorbing 700 electrical horse-power. In addition to the low-tension resistances a set of non-inductive high-tension frames is provided, which, with the instruments in connection, are capable of being used with alternating currents up to a tension of 4,000 volts. The instrument room placed at the end of the building about four feet above floor level is well supplied with standard electrical measuring instruments, and others for every-day use which are calibrated at regular intervals to ensure accuracy. A new and larger testing department is being arranged for at the new works.

BIRMINGHAM ELECTRIC SUPPLY STATION, DALE END, BIRMINGHAM.

The public supply of electricity in Birmingham is in the hands of a company who are carrying out their works under a provisional order granted in 1889. The area embraced in their operations includes the centre of the city, an out-lying district occupied by manufacturing jewellers, and the suburb of Edgbaston. The main generating station is situated in Dale End, whence current is distributed to the two out-lying districts by high-tension direct-current transformers, while the central area is supplied through low-tension mains. The Dale End station is equipped with Willans-Crompton and Belliss-Electric-Construction combined steam and dynamo machinery, from which the maximum output is equal to 1,600 kilo-watts. Steam is generated by means of six Lancashire boilers, 28 feet length and 7½ feet diameter, and four Babcock and Wilcox tubular boilers, all working at a pressure of 120 lbs. per square inch. The station is further supplemented by a battery of accumulators, of sufficient capacity to supply the present demand at the times of lowest output during the summer months, and so to reduce the running hours by one shift at this season. The out-lying station for the jewellers' district is situated 1,283 yards from the home station. As originally designed, it is now being equipped with steam machinery; and the present plan of high-tension feeding will be used only for working the station on its minor loads. The second distributing station is situated in the centre of the residential suburb of Edgbaston, 3,664 yards from the central depôt, and includes a large battery of accumulators which are charged during the day from Dale End.

The total number of 16 candle-power lamps or their equivalent on the mains amounts to about 29,000. The use of motors during the last twelve months has largely extended. Among the many purposes for which they are in demand are printing, metal working, jewellery manufacture, sewing-machine factories, lifts, &c.; and it it is found that, where freedom from smell is a desideratum, heat and vibration an objection, and space of importance, the electric motor will more than hold its own. The method of underground distribution adopted is mainly the solid bitumen system supplied by the Callender Cable and Construction Co. This plan has given practically little or no trouble, and in freedom from mechanical and electrolytic faults it leaves little to be desired. There are now 21 miles of frontages, on which energy is always available from the electric supply stations. Mr. J. C. Vaudrey is the managing director.

BIRMINGHAM SMALL ARMS AND METAL WORKS, SMALL ARMS DEPARTMENT, SMALL HEATH WORKS, BIRMINGHAM.

The rifle department was established in 1861 for the manufacture of military rifles on the interchangeable principle; and the factory now contains complete machinery for the weekly production of about 1,200 magazine rifles of British service pattern 0·303 inch bore. The system adopted is that of producing the component parts by machining alone, with the least possible amount of handwork, so that all the pieces of the same pattern shall be of identically the same dimensions; for this purpose about 2,500 machines of various classes are employed. The departments of the gun factory comprise machine shops, wood-working shops, smithy, annealing, hardening, planing, polishing, browning, and assembly rooms, together with tool and gauge rooms, etc.

The extensive machine shops are equipped with almost every form of mechanical contrivance applicable to the production of this class of work, and comprise cross milling, vertical milling, and rotary milling tools, with boring machines, horizontal and vertical drilling machines, and capstan and other lathes in great variety. In the wood-working department the machinery is specially designed to reproduce in wood an exact copy of a standard form which is attached to each machine. In the smithy there are sixteen steam stamping-hammers, twenty-four steam drop-hammers, thirteen Ryder forging-machines, five Oliver hammers, and sixty smiths' hearths. The barrel shop is supplied with drilling, turning, finishing, boring, rifling, and lapping machines, all of special design. A leading point of interest in this shop is that the barrels are drilled each out of the solid forging from one end and throughout their entire length at one setting of the barrel. The assembling, gauging, inspecting, and packing departments are all proportionately extensive. The number of hands employed by the company at its several works is now upwards of 4,000, of whom about 1,000 are engaged in the small arms department.

BOTANICAL GARDENS, EDGBASTON.

The Birmingham Botanical and Horticultural Society was founded in 1829 for the encouragement of botany and horticulture, and the instruction and recreation of the members and their families. The gardens were laid out from plans by J. C. Loudon, the most eminent horticulturist of his day, and were opened on 4th June 1832. They cover about twelve acres, upon a site which, though within a mile and a half of the centre of a city of half-a-million people, is both beautiful and rural. The natural variations of level, amounting to 50 or 60 feet, have been artistically made use of; and the surface of the great lawn, nearly three acres in area, is so beautifully moulded that the partly artificial origin of its slopes would hardly be suspected. A striking feature is the terrace of over 100 yards length, along the north side of which are the glass houses, and from which beautiful glimpses are obtained of Edgbaston, Harborne, and Moseley. This terrace with its slopes is radiant in summer with bedded flowers, while elsewhere in the gardens a natural method of planting is adopted. Below the amphitheatre of lawn is the music pavilion. Amongst other outdoor features are a rosary, a hardy fernery, and a rhododendron and azalea ground protected by a lofty beech hedge, and containing a magnificent collection of these plants. The Alpine garden was constructed two years ago at a cost of £700 for the reception of rock and bog plants, and named in memory of a former honorary secretary, the late Mr. Hugh Nettlefold, who was a member of the Institution. It covers about half an acre, and in its construction about 250 tons of millstone grit from Yorkshire were used in masses up to five tons, and about 1,000 tons of earth were moved. Many hundreds of the choicest Alpine plants are here flourishing, in spite of the atmospheric surroundings of a great city.

The glass houses, which cost about £8,000, contain plants from all hot climates; for instance, nearly 400 kinds of orchids and over 400 varieties of ferns are grown under glass. A large exhibition hall, with orchestra, provides accommodation for indoor music; and a permanent supply of electric light in the houses and on the terrace is in contemplation. Special flower shows of daffodils, pansies, spring flowers, carnations, roses, orchids, &c., are held from time to time. The curator, Mr. W. B. Latham, has been in charge for more than thirty years. The honorary secretary is Professor William Hillhouse, of Mason University College.

MESSRS. ELKINGTON AND CO., SILVERSMITHS, NEWHALL STREET, BIRMINGHAM.

The name of Elkington became identified with electro-plating in 1836, when Mr. G. R. Elkington brought out his method for depositing gold, and after a few years' practical application followed it up in 1840 by extending the process to electroplating with silver and other metals. He thus became the originator of a new industry, which speedily grew to large dimensions, and was taken up by the leading manufacturers of plate in Birmingham and Sheffield. Since his death in 1865 the business has been carried on by his descendants, Mr. Herbert F. Elkington being the present managing director.

The entrance to the manufactory up the grand staircase, which is lined with statues of the Knights who signed the Magna Charta, at once illustrates the varied kinds of work produced. These figures are the originals from which were cast the bronzes for the House of Lords, and are designed from authentic family portraits. In the spacious show-rooms is a unique display of original works of art in metal, and their replicas. Numerous studios are devoted to designing and modelling, and to the production of repoussé and damascened works; and extensive departments are set apart for chasing, embossing, and engraving.

The foundry is equipped for casting all kinds of german silver and sterling silver articles. The stamping shops contain heavy machines with their complement of dies. The electro-plating and electro-depositing departments are believed to be the largest and most completely furnished in the world. The universal brazing hearth, by which much time and labour are saved, had its origin here. The Newhall Street premises are mainly devoted to the production of works of art and the larger articles of plate, technically known as hollow ware. Table ware and cutlery are produced at the branch manufactory in Brearley Street, where much powerful machinery is in use.

NEW GENERAL HOSPITAL, STEELHOUSE LANE, BIRMINGHAM.

This building, which was opened by Princess Christian on behalf of the Queen on 7th July, is entirely surrounded by roads. It has a frontage of 348 feet in Steelhouse Lane, marked by a covered gateway of three arches, the centre for carriages, and the side ones for foot-passengers, leading into a large open quadrangle. Immediately in front is the administrative block, of which the front portion contains accommodation for the resident medical and surgical staff, a medical committee-room, and house governor's apartments. In the rear are dining rooms for the staff, nurses, and servants, the top floor throughout being occupied by the kitchen department, and the basement devoted to stores. On the right-hand is the out-patients' department, consisting of a large waiting-hall surrounded by casualty, consulting, and retiring rooms. A smaller waiting-room adjoins the dispensary. The first and second floors contain large wards with accessories, the whole forming what is known as the east pavilion.

On the opposite side of the quadrangle is the south pavilion, connected with the east by an open cloister. The ground floor contains the board and committee rooms, general offices, and waiting room, with large wards on the first and second floors.

The north and west pavilions, each containing three storeys of wards, are to the rear of a main corridor running nearly the whole length of the site. At the north-east end is a large lecture theatre, with the principal operating theatre above. Towards the south-west end are two small pavilions of three floors for burn cases, children, gynæcological, and special surgical patients. A conservatory, opening out of this end of the main corridor, forms a covered enclosed connection with the nurses' home, which is a detached building containing over one hundred separate bedrooms, in addition to sitting, writing, and lecture rooms. Behind the main buildings are some wholly isolated buildings, of which the smallest is for infectious cases developing in the institution.

Within the hospital provision is made for securing pure air and constant change throughout by mechanical means on the plenum method of ventilation. In the basement at four selected points air is drawn in through moistened screens, by which it is cleansed of suspended impurities, and brought to a state of humidity suited to the indoor temperature. In cold weather it is tempered by passing over extensive ranges of steam tubes; and by rotary fans turned by electric motors it is propelled along ducts of large sectional area to the separate flues leading up to the several wards, rooms, and corridors. At the base of each flue are additional steam-coils with regulating valves. Sufficient power is being provided for securing a complete change of air throughout the buildings from seven to ten times per hour at a uniform temperature of 60° to 62° Fahr., which can be raised to 70° when necessary. Mr. William Henman, F.R.I.B.A., is the architect, while all the ventilating and heating appliances, as well as the hot-water supply, have been arranged under the direction of Mr. William Key, of Glasgow. The hospital has accommodation for 342 patients.

MESSRS. JOSEPH GILLOTT AND SONS, STEEL PEN MANUFACTORY, VICTORIA WORKS, BIRMINGHAM.

The business carried on at these works, situated in Graham Street, was founded three-quarters of a century ago by the late Mr. Joseph Gillott, who may be termed the father of the steel-pen trade. Though not the inventor of the steel pen itself, he invented much of the ingenious machinery used in its manufacture. The metal first appears as sheet steel, which is rolled so as to be of even thinness throughout. The sheets are then cut into long strips or ribbons, of a breadth slightly more than sufficient to allow of two pens being cut out of them end to end. The strips are then passed on to the cutters, who are generally women and girls. The cutter-out sits before a small press, in which is fixed a die, having a hole through it the exact shape of the pen blank. A punch, fitting the hole to a nicety, rises and falls with the motion of the press handle, and when sufficiently depressed enters the orifice of the hole in the die. From the back of the press the end of the ribbon is placed on the die with the left hand, while with the right a little jerk is given to the handle; the punch descends, bites through the metal, and the pen blank falls through the hole. Most of the work is done by hand, but there are several large power-presses which are used when required. One of them cuts out two penholder blanks at each stroke, and punches each with three holes by the same operation. The blanks are taken to the piercing-room, where the small ornamental holes near the nib are cut out by similar punching presses. Small steel guides are fixed upon the beds of the piercing presses, by the aid of which the blank is placed precisely on its proper spot in an instant. The blanks are next annealed in shallow iron pans in a muffle or reverberatory furnace, where they are heated uniformly throughout to a dull red, and slowly cooling become so soft that they may be bent in any direction without breaking. They are then taken to the marking room. The next stage consists in raising or bending the blank into the required shape of the pen. The steel being still in a softened condition, the shaped pens are again heated to a dull red in shallow pans in a muffle, and then overturned into a bath of oil. A colander suspended in the oil brings up the pens and drains them; they are now of a greasy black appearance, and as brittle as glass. Boiling in strong soda and water removes all the impurities; and the pens are then ready for tempering. Several hundreds of grosses are placed together in an iron cylinder, which is made to revolve slowly over a number of gas jets until the required temper is obtained. They are next scoured and polished in revolving barrels, and afterwards glazed at the nibs, and finally slit. Some pens are subjected to further treatment to improve their appearance, such as browning, blueing, and plating.

In separate departments are made the cardboard pen-boxes and the wood penholders. In the latter department exhausting pipes connected with powerful blowers carry off the minutest particle of dust as soon as it leaves the wood.

The number of workpeople employed throughout the manufactory is about 350, of whom fully 20 per cent. are men.

MESSRS. JOHN HARDMAN AND CO., STAINED GLASS WORKS, NEWHALL HILL, BIRMINGHAM.

This firm was founded about fifty years ago, and its business is almost unique amongst the industries of Birmingham in its artistic nature. A visit to the works will serve as a contrast to the majority of establishments where mechanical power is paramount. Besides what has been made for home use, a large amount of stained glass has been sent to the United States, Australia, and other countries.

MESSRS. HARDMAN POWELL AND CO., METAL WORKS, KING EDWARD'S ROAD, BIRMINGHAM.

The articles manufactured at these works comprise all branches of metal work for architectural, ecclesiastical, and domestic purposes. The first metal work was produced by this firm in 1838, and from that time until 1845 the work was almost all of an experimental character, the art of working in metals on true Gothic principles having entirely died out in this country. By the unfailing energy of Augustus Welby Pugin, who was ably supported by the late John Hardman, the many difficulties were gradually overcome, and works were opened in Great Charles Street, Birmingham, in 1845. From that time they have been steadily expanding, and although the vast majority of work done here is essentially handwork, they have some good machinery and modern appliances, the use of which in no way detracts from the artistic treatment of the work. Examples of the work of this firm can be seen in most of the cathedrals and churches of England, the houses of parliament, and many other public buildings throughout the country.

MESSRS. J. H. HOPKINS AND SONS, GRANVILLE TIN-PLATE WORKS, BIRMINGHAM.

This business of tin-plate working was established in 1850 by the late Mr. John Head Hopkins in partnership with his son Mr. J. Satchell Hopkins. The manufactory was specially planned and built for the trade in Granville Street; it was subsequently much enlarged, and at different times since adjacent premises in Berkley Street, Holliday Street, and William Street, have been added thereto. Such great alterations have taken place in the trade of tin-plate workers in the last sixty years that the original name of the trade has ceased to be its most correct designation at the present day. The number of articles now manufactured by the various processes in use has increased at least tenfold. The sizes of the separate articles have been enlarged much in the same proportion; for instance pudding pans, washing bowls, milk pans, &c., formerly made in small pieces grooved or jointed together, and then hardly ever of a greater diameter when finished than 12 or 14 inches, are now made in one piece of a finished diameter of 20, 30, or even 40 inches. And instead of being made of tin plates, the articles are made of black-steel sheets, and coated with best block tin as a final process and finish. These alterations have been accomplished by improved machinery. The late Mr. Thomas Griffiths, the senior member of the firm originally known as Griffiths and Hopkins and afterwards from 1850 and for many years following as Griffiths and Browett, was the first to introduce with good practical result steam-machinery for stamping, spinning, and burnishing. Immense improvements have been made in the machines employed for all these processes, first by the French makers who used a pressure plate and a gradual forcing process by screw-presses, instead of a number of sharp blows under a stamp hammer as in the English method. Improvements in stamping nevertheless kept the English makers well abreast of their French competitors for many years. Twenty-five years ago Mr. Satchell Hopkins entered into communication with an English engineer then long resident in America, who had invented and put up some new and improved machines in New York; and under their joint superintendence pressure-plate presses and machines for spinning, forming, trimming, wiring, &c., were erected at these works. These were the first machines of the kind erected and used in this country, and except in some minor points indicated by continued experience have never yet been improved upon. One of these machines, erected twenty years ago, is still the largest and most powerful of its kind. An interesting series of machines, working automatically, are here in use for the manufacture of galvanized-iron buckets, which are produced by what is virtually a single operation.

Many things now done in this trade have been rendered possible only by the great improvement in the manufacture of black-iron and black-steel sheets. Steel is fast superseding iron entirely; and although the old nomenclature remains, it is no longer correct to speak of japanned tin boxes or baths, as these articles are now all made out of steel sheets, and are finished by tinning and japanning. Sixty years ago the largest black-iron sheets that could be produced were 24 inches wide and 72 inches long, though length was not bounded by the same difficulties as width. Sheets can now be rolled 72 inches square or 72 inches wide by 8 or 10 feet long. This improvement in material and rolling machinery in iron works may be considered the second great factor in the expansion of the stamped or pressed sheet-iron or steel tinned hollow-ware trade. These large steel sheets can now be coated with tin with a perfection of finish equal to that of the smallest sizes; and this has greatly developed the production of milk trendles, which now crowd the railway stations of our large towns.

An important part of this business is and always has been the japanning and decorating of tea trays, waiters, coal boxes, grocers' canisters, &c. In this department the hard shiny and brittle japan of former days is being superseded by the firm's stannic enamel, a material of remarkable elasticity and durability, which has somewhat the appearance of leather, and is much better adapted for artistic decoration. The number of workpeople employed is about 400.

LLOYD'S PROVING HOUSE, NETHERTON, NEAR DUDLEY.

This establishment, licensed by the Board of Trade for the testing of chain cables, chains, and anchors, was commenced in 1865 with one small building about 140 feet long by 50 feet wide, and one testing machine; and by subsequent enlargements and the addition of more powerful machinery, to meet the requirements of acts of parliament, and of the rapidly developed chain, cable, and anchor trade of the district, it has become the largest and most complete of its kind in the kingdom. It is laid out for testing every description of chains and anchors, from short-link chains of $\frac{1}{8}$ inch diameter to the largest cables, mooring chains, and anchors, used either in the navy or in the mercantile service. It is also fitted for experimental testing of every description; and here were tested specimens of riveted joints for the Research Committee of the Institution of Mechanical Engineers (Proceedings 1888, page 538).

The testing machinery consists of five machines, of 50, 105, 150, 200, and 300 tons capacity. The 50, 105, and 200-ton machines are used for testing the whole chain, in a length not exceeding 90 feet, and also for anchors; the 150 and 300-ton machines are used for testing the trial pieces, cut out of each 15 fathoms, or less, of cable, to comply with the statutory requirements, and also for experimental purposes. By law it is required that a ship's cable shall be made up of lengths not exceeding 15 fathoms, being joined together to complete the cable by means of shackles, the bolts of which can be readily driven out at any time when the ship is riding at anchor, for enabling her to slip her cable if necessary. From each length a trial piece of three links, chosen by the superintendent of the proving house, is cut out, and is subjected to the appropriate breaking strain, for ascertaining the quality of the iron and workmanship; and then, if found to be satisfactory, the whole length is tested to the corresponding tensile strain. The links are cut out by hydraulic shears, and the appropriate breaking strain fixed by parliament for cables varies from 40 to 50 per cent. above the tensile strain; but cables of high-class quality usually withstand a much higher breaking strain.

The 300-ton machine is the most powerful of its kind in the country, being specially adapted for experimental testing of chain cables and of iron and steel; it is adapted for applying either tensile, compressive, bulging, torsional, or transverse strain, provision being made for the preparation of experimental samples, either by lathe or by shaping, slotting, or planing machine. There is also an apparatus for obtaining the limit of elasticity of metals. Chain cables up to 3½ inches diameter have been tested and samples broken; and anchors exceeding 10 tons, made in the district, have been tested here, a steam travelling-crane being used for lifting and moving the heavy articles.

The whole establishment is lighted by electricity; four 1,000 candle-power arc lamps and a number of incandescent lamps are used for this purpose. The examination also of cables and chains after testing is done by the electric light during the winter months and in dull weather; a 50 candle-power incandescent lamp is fixed on the front of each examiner's cap, so that the work can always be kept going. For ascertaining the correctness of the centre lines of the different levers of the machines, a true plane surface-plate is used, 18 feet long by 8 feet wide, which is rather unique of its kind. The capacity of the establishment, which is usually kept in regular operation, is equal to testing 250 tons per week of chains, cables, and anchors. The number of men employed is about 60.

The company have a similar establishment of less capacity at Tipton, started in 1864, and licensed by the Board of Trade for testing chains, cables, and anchors. There are three testing machines of 50 and 105 and 150 tons capacity. The 50 and 105-ton machines are for testing the whole chain in a length not exceeding 90 feet, and also for anchors; and the 150-ton machine is used for testing the trial pieces, and for experimental testing of iron and steel. This establishment is lighted by the electric light in a similar manner to the Netherton proving house. Its capacity is approximately 150 tons per week of chains, cables, and anchors. The number of men employed is about 30; Mr. H. Green is the superintendent.

MASON UNIVERSITY COLLEGE, BIRMINGHAM.

The late Sir Josiah Mason had long felt the importance of providing enlarged means of scientific instruction for the manufacturers of the town and district, upon terms which should render it available to persons of all classes. By means of his own indomitable energy and force of character, without any advantages of education, he had himself risen from a humble position in life, and had become the founder of large industries and had attained to great wealth; and recollecting his own disadvantages and struggles, he wisely and generously determined to devote a large portion of his wealth to the provision, for those who came after him, of that scientific and literary training of which he had so keenly felt the need. After six years of preparation and negotiation, the foundation deeds were executed, the site purchased, and the plans of the building approved; and he had the pleasure of laying the foundation stone of the new College on 23rd February 1875, the eightieth anniversary of his birthday. The building was completed and the College ready to receive students on 1st October 1880. He was present at the opening ceremony, and survived until the following June. The deed of foundation provided originally for scientific instruction only, with the addition of the English, French, and German languages;

and by subsequent deeds the founder varied and extended the scheme so as to authorise the trustees to provide instruction in all branches of science (including medicine and surgery), in art, in languages and literature, and in all subjects required for degrees in arts or science. The deed provides that "no lectures or teaching or examinations shall be permitted in the institution upon theology or any question or subject in its nature purely theological, or upon any questions which for the time being shall be the subject of party political controversy."

The site of the College extends from Edmund Street to Great Charles Street, and comprises about an acre of land with a frontage of 150 feet towards Edmund Street and a depth of 313 feet. The frontage is in one side of a square, of which the other sides are occupied by the Town Hall, the Council House and Corporation Art Gallery, and the Free Libraries; the College is thus situated in the centre of the municipal life of the city. The building was erected under the personal direction of the architect, Mr. Jethro A. Cossins, assisted by Mr. Hodgkiss, a practical builder, and a relative of Sir Josiah Mason by marriage, who acted as clerk of the works. The cost of the site was £20,000, and a sum of £60,000 was expended on the building and its fittings.

The buildings, four storeys in height, are arranged in two blocks, connected at each side by wings, and divided in the centre by main corridors which look into two open courts. The material is red brick and stone; the style is Gothic of the thirteenth century, with details largely derived from French architecture of that period. The accommodation includes four lecture-theatres, the largest 50 feet by 33 feet; laboratories for each of the science departments, the largest (that for chemistry) being 104 feet by 32 feet; three museums devoted to zoology, geology, and engineering; a library about 65 feet by 30 feet, containing upwards of 24,600 volumes, to which all day students have free access; ample and numerous class-rooms and administrative offices; a common room for students; and all other appliances necessary for the comfort of professors and students. For the women students there are separate retiring and reading rooms and lavatories.

The endowment provided by the founder, including the cost of the site and buildings, amounts to close upon £200,000; the annual income derived from the various investments is nearly £4,000 a year. A total sum of £25,000 is now granted every year by the Government to the various provincial university colleges, of which £2,700 falls to Mason University College. The College is still urgently in need of funds for the library and museums, and for the better equipment of laboratories.

In 1892 the Medical Faculty of Queen's College was transferred to Mason University College, the necessary accommodation having been provided at a cost of upwards of £18,000 by the erection of new buildings, which, facing Great Charles Street on the one side, are continuous with the original buildings of Mason University College on the other. The new buildings contain a dissecting room, 91 feet long by 27 feet wide, with which are continuous a large lavatory and coat room, and a room for the chief demonstrator. The anatomical department also consists of a theatre seating 223 students, with professors', demonstrators', and prosectors' rooms, museum, and preparing rooms. There is a general medical theatre seating 326 students, with professor's retiring room and lavatory. There are also museums of pathology (46 feet square), materia medica, public health, and dentistry, with bacteriological and dental laboratories. On the ground floor are the Dean's office, janitor's rooms, and general hat and coat and locker room with lavatory. A common room for the students, in common with those of the other Faculties, forms part of the new buildings. Besides these additions there already exist in the College complete departments of physiology—for which the accommodation has recently been considerably extended—chemistry, physics, and zoology.

In the first year of College work there were 95 students. In 1895–6 there were 689 individual students in the day classes, and 411 individual students in the evening classes.

MIRROR LAUNDRY, HARBORNE, BIRMINGHAM.

This laundry was built and equipped by the Mirror Laundries Co. in 1894–5. It consists of a main building 86 feet long by 80 feet wide, with attached boiler house 30 feet long by 20 feet wide. In the front of the main building are the sorting and packing rooms, offices, and delivery lobby; above is a mess room for the workpeople, and a collar-ironing room. The rest of the building is divided into three bays, which constitute the wash-house, machine-ironing, and hand-ironing rooms. At the end of the wash-house are the engine room and store room; and a row of dry horses, with curtain and blanket room above, occupies one end of the machine-ironing room. The washing and ironing machinery, &c., has been supplied by various makers; and a compound vertical engine with 6 and 10 inch cylinders and 10 inch stroke, specially designed by the company's engineer, supplies the motive power. A Galloway boiler for 100 lbs. per square inch working pressure supplies steam to the engine and throughout the laundry generally. The consulting engineer and managing director is Mr. E. Fuhrmann Clarke. The number of workpeople employed is about 100.

MESSRS. HENRY MITCHELL AND CO., CAPE HILL BREWERY, BIRMINGHAM.

This brewery, situated in Smethwick, was established in 1865. The boiler house contains four Lancashire boilers, one Cornish, and one tubular boiler; the six work three horizontal engines of 7, 14, and 24 horse-power. In the engine house are two boiler feed-pumps, and two sets of three-throw gun-metal pumps. An artesian well in the yard, 270 feet deep, contains three sets of three-throw pumps, capable of raising together 12,000 gallons per hour; and in the tower are two large iron cold-water tanks, each having a capacity of 6,000 gallons. The mill room contains two malt-grinding mills, each capable of crushing 120 bushels of malt per hour, with screening and grading accessories; and an iron tank holding 7,500 gallons of cold water. In this room are also two hot liquor tanks of 4,500 gallons capacity each, and two of 1,800 gallons each, all of which are fitted with steam coils. In the mashing room are three mash tuns capable of mashing a total of about 2,240 bushels of malt; each tun is fitted with outside mashing machine and internal rake machinery. In the copper house are four boiling coppers, each having a capacity of 3,600 gallons. The hop-back room contains a circular copper hop-back of 7,200 gallons capacity, with gun-metal false bottom; also a copper well connected by a main with the wort pumps in the engine house. There are three upright refrigerators, having a combined cooling power of 3,600 gallons per hour. In three rooms on the top floor are twenty-two collecting and fermenting vessels, each having an average capacity of 6,840 gallons, and each vessel fitted with refrigerators and mechanical agitators. The cleansing rooms contain sixty-four cleansing vessels, varying in capacity from 3,240 to 3,600 gallons each, fitted with parachute skimmers and refrigerators. The barm cellars occupy the ground floor under the cleansing rooms, and contain slate tanks for yeast storage. About 10,000 barrels of beer can be stored in the brewery. In the racking room, where the beer is drawn off from the lees, are four tanks fitted with the necessary accessories for filling barrels. The bottling stores contain bottling apparatus, and bottle-washing and corking machines. In the hop and malt stores are a series of bins, each capable of storing from 4,000 to 5,600 bushels of malt; and spaces for storing hop bales and pockets. The number of men employed is over 400.

NATIONAL TELEPHONE CO., BIRMINGHAM.

The principal Birmingham telephone exchange of the National Telephone Co. is at present situated at 40 Bennetts Hill; but handsome and extensive premises are being built at the corner of Newhall Street and Edmund Street, in which it is trusted that the Central Telephone Exchange, with entirely new switching plant, will be working sometime next year.

The exchange is practically divided into two parts: namely a local room, where all the local calls are dealt with; and a junction room, where the calls for subscribers on other exchanges in the area and trunk calls are attended to. Forty-seven operators deal with the messages, which according to the latest statistics amount to 208,200 per week, or considerably over 30,000 per weekday.

The principal feature of the multiple board is the arrangement whereby each subscriber's line on the exchange is so placed that it comes within the reach of every operator in the switch-room; and this is effected by multiplying the lines in each section of the switch-board; on the Birmingham board there are ten sections, accommodating 2,000 subscribers' lines. The importance of this multiple arrangement will at once be seen, when it is remembered that, although the operator has only to answer the calls in the section allotted to her, nevertheless her various subscribers will naturally be requiring to speak to any other persons connected with the exchange. An important and necessary feature of the multiple board is the "engaged test." It is obvious that, as every subscriber appears before the various operators, several callers might be put on to the same number at once. In order to prevent this, the board is specially wired so that the test wire is connected to the earth throughout the whole series of the subscribers' jacks, and a recognised signal is received by the operator in such cases. Before making a connection, the practice is to touch the front of the jack with the tip of the connecting plug: if the subscriber is engaged, the operator receives a sharp clicking sound in her ear; if the subscriber is disengaged, no sound is heard, and she makes the connection. Each operator is provided with a head-gear receiver and breast-plate transmitter, made principally of aluminium; these are very light, and greatly aid the operator, as they leave both hands free and allow her to move in any desired direction while yet having the apparatus always with her.

As the Birmingham Centre covers a considerable area, there are nine sub-exchanges, which collectively require twenty-seven operators; and others are in course of construction. In order to obtain inter-communication between the central and sub-exchanges, there are a number of junction wires with call wires between the various points. At the receiving ends, the call-wire operators are situated at their respective switch-boards with their telephone receivers to their ears; and at the sending ends, tapping studs or keys are provided, so that the operator at one exchange can gain the attention of the operator at the distant exchange, and obtain without loss of time any connection which may be required. The company have instituted and are extending an arrangement of visual signals, whereby the plugging or unplugging of the various junction lines is indicated instantaneously at both ends of any particular wire. The wires are brought on to the test board, which is in an adjoining room, through suitable springs, whereby the test clerk is enabled to make rapidly such connections as may be necessary in order to test the nature of any fault and localize it. Lightning protectors of a compact and efficient form are also provided. There is an extensive system of underground wires, ranging from earlier makes of cable insulated with gutta-percha to the most modern paper cable enclosed in a lead sheath, which may be seen in the cable terminal room. On the roof is the derrick carrying the overhead wires; and a good bird's-eye view of the city and the ramifications of the telephone system may be had therefrom.

MESSRS. F. AND C. OSLER, CRYSTAL GLASS WORKS, BIRMINGHAM.

This firm, which was established in 1807, has two works in Birmingham: one in Freeth Street, where the glass is made, blown, and shaped into the many different articles; and the other in Broad Street, where the glass is cut and engraved. The materials used in glass-making are sand, red lead, potash, and saltpetre. The glass house is in the shape of a cone, and the furnace is constructed in the centre of the area; it contains from ten to twelve melting pots, which are composed of Stourbridge clay and are each capable of holding about 18 cwts. The process of melting lasts about two days; and when the glass—or metal, as it is usually called—is properly melted, the work in the glass house begins, and is continued night and day until the metal is exhausted. After any article has been shaped, it goes through a process of annealing, which generally requires from 24 to 96 hours according to the size of the article; afterwards it is sent to the Broad Street works for cutting.

The cutting is done on revolving wrought-iron discs driven by machinery; a hopper containing sand and water is fixed immediately above each disc, and the contents are allowed to run in a continuous stream upon the revolving disc. By this means the pattern is "roughed" upon the glass. It is next "smoothed" by a similar process, except that a smooth stone is used instead of an iron disc, and the sand is dispensed with altogether. After passing through these two processes, it only remains for the work to be polished by means of wooden wheels and rotten stone; and finally the article is brushed over with oxide of lead, which gives it a fine lustre.

MESSRS. OSMONDS,
CYCLE WORKS, THE TOWER, BIRMINGHAM.

This firm is the outcome of the Osmond Cycle Co., which was established in 1894, in the commodious premises known as The Tower, situated at the corner of Bagot Street and Lancaster Street, Birmingham, and previously used as a small-arms repairing factory. High-grade machines only are built, for which all the component parts—with the exception of tyres, saddles, chains, and rims—are made on the spot, and are absolutely interchangeable. Each department is kept entirely separate, and the most rigid system of viewing is in force.

The shops are as follows:—machine, building, filing up (two), brazing, polishing, plating, enamelling, hardening and annealing, wheel, gear case, assembling and finishing; in addition to which there are the tool room, view room, packing room, two smithies, rubber, general, and component stores. In the machine shop all components are dealt with by the following machinery:—milling machines, capstan lathes, hub machines, drilling, screw-making, turning, chain-wheel making and cutting, grinding and lapping. In the building shop all frames, forks, and mudguards are built. The use of inside liners for the necessary frame joints has been discarded in favour of bushed joints. The hardening and annealing are done on the latest method of heating by gas. The plating shop is equipped with a most complete electro-plating installation. Gas is produced in the works on Dowson's plan, which works well, and is especially satisfactory in the enamelling shop. A portion of the yard has recently been covered in with a glass roof, and converted into a shop containing two lines of shafting for additional machinery. The motive power consists of two Crossley gas engines. The total area of shopping, on three floors, is 34,848 square feet, and of yard space 17,044 square feet; and the number of men employed is between five and six hundred.

GUN PROOF HOUSE, BANBURY STREET, BIRMINGHAM.

The Birmingham Gun Proof House was built in 1813, by public subscription, afterwards repayable, in pursuance of an act passed in that year "to ensure the proper and careful manufacturing of fire-arms in England." Scales for suitable charges of powder and lead were framed, and proper proof marks were designed to be stamped on such barrels as stood the required proof. In 1815 an amended act was passed; and in 1855, in consequence of many improvements in fire-arms, a further act was passed, making new regulations suitable to the improvements. In 1868 an amended proof act came into force, controlling by strict regulations the condition of the arms when presented for proof, the strength of the powder employed, the specific gravity of the lead, and the kind of wads used. The ordinary gunpowder is received fresh about twice a week, and tested. The magazine and safety appliances are from time to time visited without notice by H. M. inspectors of explosives. The heating of the rooms is by hot-water pipes.

Arms are generally proved at two stages of manufacture: first, when the barrels are bored nearly to size, and dressed ready for fitting up; and secondly, when they are connected with the rest of the mechanism, and ready for stocking. The proof charges are generally proportional to the area of the bore of the barrel, and are regulated so as to produce a final stress of about 80 per cent. in excess of that of the ordinary service charge. The stresses are estimated by crushing copper or lead cylinders, through the medium of pistons passing through the thickness of the barrel just to the inner surface of the bore. The cylinders are placed on the heads of these pistons, and caps are screwed just down on to the cylinders. On firing the gun, the powder gas, acting on the pistons, crushes the cylinders against the caps screwed on to them, and the amount of shortening of the cylinders indicates the stress exerted where they are situated on the barrel. From the varying violence of the many new gunpowders, much attention is at present directed to ascertain the absolute radial or bursting stress exerted by a given charge of powder and lead in a barrel at different distances along it from the breech or point of ignition. The interval of time from the ignition of the percussion cap to the exit of the shot from the muzzle of an ordinary sporting gun barrel 30 inches long, with 1,250 foot-seconds muzzle-velocity, has been estimated at about half a hundredth of a second. Inasmuch as the important factor of the time in which the crushing is done is so difficult to ascertain, it is disputed whether the momentary stress on the crushing pistons is an impact or a pressure, and therefore whether it should be expressed in gravitation terms of foot-lbs. per second, or in tons per square inch. Many expedients have been devised for ascertaining the time, but so far no absolute measure which is trustworthy has been arrived at. For the comparative stresses the crusher gauge is the best measure yet invented. In the test of a gun for sporting powders the pistons are fixed at 1 inch, 2¾, 6, and 9 inches and other points from the breech face. The muzzle velocities are found by Boulenge's chronograph, and the momenta of shot by swinging targets on the pendulum principle. The gun is loaded with powder in the first proof by measures, and with a spherical ball nearly the diameter of the bore; in the final proof, shot is used instead of ball. A felt wad is placed on the powder and on the lead. In the first proof, three times the service charge of powder is used, and in the second proof the excess stress over that of the service powder and lead is found and applied. The relative violence of powders greatly affects the proof quantity. In ramming the charge down, the barrel is set upright behind a thick plank, in front of which the rammer stands, and draws down a metal ramrod, which slides in a vertical groove in the plank; by this plan he is safe from accident.

For firing in the first proof, about 120 barrels are laid in grooves on a lead-covered bench in an iron-plated room, and then are fired into a bank of sand about 8 feet distant. They are laid touch-holes downwards, with a train of powder beneath them; when fired they recoil into a bank of sand. They are then washed clean in hot water, and when dry are viewed for cracks and bulges. Great experience is needed to detect the defects when slight; and however small a hole or crack may be in the commonest barrel, it is rejected. In cases of doubt, the barrel is set up between two centres, one of which is a tube, and water is pumped in till a hydraulic gauge indicates 600 lbs. per square inch; the water will then show itself through the most minute defect in the barrel. If perfect, the barrels receive the proof mark, and are delivered to the owner.

In the final proof, the breech mechanism is attached to the barrel, and mounted on an iron wagon to permit of recoil. The ignition of the cartridges is effected by a hammer fixed on the wagon, and actuated by a leather thong outside the firing room.

The ordinary number of proofs is now about a thousand a day; in war times it has reached three times that amount. The complications of modern guns of all kinds, and the careful weighing of the proof charges of the modern violent nitro-powders, have rendered the time of proving considerably longer than formerly. Mr. Samuel B. Allport is the proof master.

Power is given in the act of parliament to adapt the proof regulations to modern requirements in arms and ammunition, on the approval of the Secretary of State for War.

The Gun Makers' Company of London, established by Royal Charter, have also a proof house, with working regulations the same as in Birmingham.

MESSRS. P. WEBLEY AND SON, GUN MANUFACTORY, WEAMAN STREET, BIRMINGHAM.

This business was commenced in 1817 by Mr. William Davis, grandfather of the present proprietors, for the manufacture of gun implements and materials. Up to the time of the introduction of breech-loaders, no rifle was complete without a bullet mould and patch punch with the initials W. D. In 1845 the business was bought by his son-in-law, Mr. Philip Webley; and in 1858 it became known by the present name of the firm, having meanwhile, with the growth of breech-loaders, changed into the manufacture of guns and rifles, and later of revolvers also. These are practically the only works making revolvers in this country, and have occupied a staff of government viewers for the last eight years inspecting revolvers made for the whole of the land, naval, Indian, and Colonial forces.

New works running through into Slaney Street have recently been built adjoining the old premises, which are about to be pulled down for further extension, so that the original building No. 84 has grown from No. 81 to 91 Weaman Street, running through into Slaney Street. In the factory is a large collection of modern machine-tools, which are used in the manufacture of the revolvers on the interchangeable system. Target rifles for volunteers are also made; and in addition the firm are wholesale manufacturers of sporting guns and rifles. The number of persons employed has grown from 10 to about 500.

MESSRS. WINFIELDS, CAMBRIDGE STREET WORKS AND ROLLING MILLS, BIRMINGHAM.

These works, which are situated near the centre of the city, were founded in 1820 by the late Mr. Robert Walter Winfield, who commenced by making stair rods in a small block of shopping in Cambridge Street; the business rapidly increased, and the premises were greatly extended, other branches being added from time to time.

The present works cover an area of 4½ acres, with a frontage of 830 feet, extending from Baskerville Passage at the top of Great Charles Street, along Cambridge Street, to King Alfred's Place; and they are divided into various departments.

The raw-material section consists of strip casting-shops, metal rolling, wire drawing and tube mills, which are driven by an engine of 150 H.P. supplied by two large boilers. The principal goods manufactured in the department are brass and copper strips and sheets, brass and copper tubes, and brass and copper wire, of which large quantities are turned out. The gas and electric-light fittings and brassfoundry department includes the making of all kinds of small gas and water fittings for indoor and outdoor application, all kinds of ornamental fittings in brass, copper, and wrought-iron for gas and electric lighting, such as brackets, chandeliers and electroliers, for private houses or public buildings, and almost every variety of general brassfoundry. The bedstead department is one of the earliest in which metallic bedsteads were made. The late Mr. Winfield commenced making brass and iron bedsteads, and by elegance of design and many other attractive features succeeded in so far developing this branch that many thousands of bedsteads had been turned out here before other makers took up their manufacture. The motive power for the gas-fittings and bedstead departments is supplied by two engines of 150 and 50 horse-power.

In addition the works include carpenters' and engineers' shops, the repairs to buildings and machinery being done by their own men, as well as the manufacture of the packing cases used in the business. A coal wharf at Browning Street supplies the fuel for consumption in the works, and a considerable coal trade is also done in the city. At these works practically everything is done from the casting of the metal to the turning out of the various finished articles, of which examples are on view in the show rooms. Lacquer is also manufactured in large quantities for use in the works, and for supplying the leading brass manufactories in the country.

GREAT WESTERN RAILWAY LOCOMOTIVE WORKS, STAFFORD ROAD, WOLVERHAMPTON.

These works, established in 1849 by the Shrewsbury and Birmingham Railway Company, which was afterwards amalgamated with the Great Western Railway Company, are situated near Dunstall Park station, on the main line from London to Birkenhead; and are used for the manufacture and repair of locomotive engines and machinery. They comprise iron and brass foundries, forge, smithies, turning, erecting, carpenters', and pattern-makers' shops; and are fitted with modern machinery, and travelling cranes worked by cotton ropes and friction gear. Since they were opened 642 new engines have been constructed, and about 250 engines are repaired yearly. There is also a large engine shed, and upwards of 110 engines are in steam daily. Over 1,000 men are employed in the works, and upwards of 500 in the running department. There is a mechanics' institution connected with the works, comprising reading room, library, and billiard room, and a cricket field attached. The works are under the charge of Mr. W. H. Waister, assistant locomotive superintendent.

ELECTRIC CONSTRUCTION CO., BUSHBURY ENGINEERING WORKS, WOLVERHAMPTON.

The present works at Bushbury stand on a site of about 23 acres. They were erected in 1889, and the buildings, which cover an area of upwards of four acres, were specially designed for turning out heavy electrical engineering work with facility and expedition. The whole of the shops and offices are on the ground level, with the exception of one first floor for light instruments and arc lamps. The roofs are of glass and iron, supported on the cast-iron columns which carry the traveller gantries, so that there is little or nothing of a combustible nature. As a further safeguard, the pattern shop, foundries, and smiths' shop are detached from the main buildings, as are also the physical and chemical laboratories.

The iron foundry is equipped with three cupolas, capable of turning out 25 tons of castings per day, air being furnished by a Root's blower driven direct by an electric motor. The floor is served by an electric overhead 10-ton traveller, and by two smaller 5-ton travellers. Recently a ring for a fly-wheel magnet, in two pieces, each weighing 11 tons, has been cast for the Halifax lighting station; these castings can be seen in the machine shops. The brass foundry adjoining has eight furnaces, and turns out a large quantity of plate moulded work.

The power house contains four water-tube boilers working at 150 lbs. per square inch, which supply steam to a Robey compound engine of 150 I.H.P. driving by a belt an 80 kilo-watt dynamo, and also to a Willans engine coupled direct to an 80 kilo-watt dynamo; the two dynamos are run in parallel to supply the motor and lighting power. The whole of the shops are driven by motors, usually belted to short lengths of shafting, but in several cases driving individual machines. There are also two other engines, one of 200 I.H.P. and the other of 100 I.H.P., which are used for testing.

The main erecting bay is served by two electric travellers, having a span of 45 feet and a travel of nearly 300 feet, which is the length of each of the bays. It is equipped with several fine machine-tools, notably a planer by Whitworth, capable of taking work of the largest size, a face-plate lathe by Muir for work up to 18 feet diameter, and several horizontal boring machines and other lathes. In this bay and elsewhere are to be seen parts of several machines of exceptional size, including 300 kilo-watt alternators, 400 and 1,700 kilo-watt continuous-current dynamos, and variable-ratio transformers &c.

The press shop, situated to the left of the main bay, is full of punching and cropping tools of every description. Here the armature cores are built up, and the transformer laminations cut. Overhead is the meter and arc-lamp shop. Of the remaining bays to the right, nos. 2 to 5 inclusive are equipped with high-class machine-tools of the usual description, including lathes, planing, slotting, shaping, drilling, milling, and profiling machines. Bays 6 and 7 are winding shops. Here a number of girls are employed in insulating the iron laminations, and doing light winding work on alternate-current transformers. Instead of the older style of drum winding, in which each coil crossed over all the preceding ones, an improvement is here seen in the Eickemeyer systematic armature winding, whereby the coil is wound independently of the armature core, and is readily insulated for any necessary pressure; and all coils on an armature are exact counterparts, capable of ready removal and replacement. The brass finishing shop contains numerous turret lathes, universal millers, screwing machines, and others, driven from two shafts, each with its own motor. Machinery from these works is found already in most of the lighting stations throughout the country; and among the larger work in hand at the present time are alternators, dynamos, elevators, lighting plant, locomotives, tramway motor equipments, re-winding of dynamos to suit high-voltage lamps, transformers both alternate-current and continuous-current rotary. Enclosed factory and tramway motors, of which examples can be seen in progress, are meeting with much success. The number of workpeople employed is at present about 720; for their use a convenient mess-room is provided on land belonging to the company outside the works proper. Another portion of land is divided up into allotments, and let at low rates to those workpeople who have a taste for gardening. The engineer and manager is Mr. A. B. Blackburn.

MESSRS. THOMAS PARKER,
ELECTRICAL ENGINEERING WORKS,
WOLVERHAMPTON.

These works are situated on the Wednesfield Road, within five hundred yards of the railway stations. They were built in the latter part of 1894, and some extensions have recently been made. They comprise in independent buildings:—iron and brass foundries; pattern-makers' and smiths' shops; main shop, 250 feet long by 150 feet wide, in which are the machine-tool, erecting, winding, and testing departments; and stores. The offices adjoin the main shop. The whole of the works including the power cranes are driven electrically; and the lighting by arc and incandescent lamps is also supplied from the same generating plant. Most of the machine-tools are driven from line shafting; but some lately added have each their own motor. The works are employed solely in the manufacture of dynamos, motors, and switch gear, &c.; and furnish complete equipment for electric lighting, electric railways, tramways, and power transmission. The number of workpeople at present employed is about 400.

CORPORATION ELECTRIC-LIGHT WORKS, WOLVERHAMPTON.

The erection and equipment of these works was completed in January 1895, when they were formally opened by Lord Kelvin; and since that date the supply of electricity has been continuously maintained. The present capital expenditure has been £38,000, with a capacity of 15,000 lamps of 8 candle-power. The buildings at present consist of a main generating station and three sub-stations. The system of supply is the high-pressure continuous-current. The current is generated at 2,000 volts pressure, and is distributed by high-pressure mains to the outlying sub-stations, where it is transformed by means of motor transformers down to about 110 volts, at which pressure it is distributed to low-pressure mains, and thereby to consumers' premises. The plant at the generating station consists of four complete generating sets, each comprising a horizontal compound condensing engine and a separately excited continuous-current dynamo with a rope-driven exciter. Three of the four sets are of 140 kilo-watt capacity, and the fourth of 65 kilo-watts; all four are rope-driven, and each can develop 2,200 volts. The dynamos are two-pole inverted. The condensing plant consists of a Ledward ejector-condenser, and a centrifugal pump driven direct by a vertical steam-engine for raising the condensing water from a canal. The boiler-house contains three Lancashire boilers, two economisers, pumps, &c.; and steam is generated at 130 lbs. per square inch. The chimney is 100 feet in height, and is of circular section throughout inside. A water-softening apparatus is in use, having a maximum duty of 300 gallons per hour. The high-pressure mains consist of vulcanized bitumen cables laid in iron troughs, which are filled in with bitumen and closed with a water-tight iron lid. The low-pressure mains are armoured single-conductor cables buried in the ground. The sub-station at the Town Hall performs a quadruple duty: it serves as a central switching station, takes its share of the transforming, controls the arc-lighting circuits, and deals with a battery of accumulators. It is equipped with three motor transformers, each giving 400 ampères at 110 volts for the general supply; one arc-lighting transformer for splitting the 2,000 volts into two of 1,000 volts on two separate circuits; and one booster for supplying some 40 volts extra for the charging current for the battery. The battery has a specified capacity of 600 ampère-hours. Mr. F. Harman Lewis is the borough electrical engineer.

MESSRS. EDWIN DANKS AND CO., OLDBURY BOILER WORKS.

These works are situated at Oldbury, about five miles out of Birmingham, close to the Great Western and London & North Western Railways and the Birmingham Junction Canal. They are compactly arranged on a site of 5½ acres, including yard space. The present buildings include drilling and planing shop, boiler-shell marking and bending shop, erecting, shell-drilling, and fitting shops; whilst the large yard affords ample space for boilers awaiting despatch, and for the storage of flues, shell plates, and other parts of boilers after they have been welded or bent up ready for fitting into the complete boiler.

In the drilling and planing shop are piles of plates waiting to be dealt with. All the flue-plates are first brought here to be scarfed for welding. Amongst the tools are a large plate-edge planing machine for planing tank-plates, a drilling machine for stand pipes and manhole lids, and a flue-flange drilling machine, originally intended for drilling flanged-joint holes but now used for turning the edges of flue-flanges. In a shed forming a continuation of this shop are steam-hammers and fires, where sections of the flues are rapidly welded up.

In the boiler-shell marking and bending shop the plates are marked, sheared to length, and the blockholes and manholes bored out under the machines. They are then taken to the hydraulic press for setting, and passed through the vertical rolls, by which they are bent to shape. This machine is of the three-roll design, and has its own pair of engines attached for driving. Close by is a hydraulic press, capable of exerting a pressure of 400 tons; a set of four-throw pumps supplies the water at a pressure of three tons per square inch. In this department is a set of horizontal rolls to admit plates 8 feet wide, and a smaller set for bending the flue-plates before welding; two machines for flanging the edges of the flue-plates; machinery for bending angle-iron rings; and a blower, which provides blast for the welding fires. In the yard is a flanging furnace for end-plates, which admits a plate 9 feet diameter. A 35-ton overhead steam-traveller is here in use; and eleven of these cranes of various capacities are employed in different parts of the works. A pneumatic caulker can be seen at work in the yard; the head of the tool is held up to the boiler and passed along the joints, whilst a rapid series of smart blows automatically delivered effectively closes the joints.

The erecting shop contains a number of portable hydraulic riveters; also a stationary riveter placed under a tower, where the longest boiler casing can be dealt with. The boiler-shell drilling shop, about 200 feet long by 50 feet wide, is equipped with a powerful overhead crane driven by square shafting; a large butt-drilling machine capable of drilling four holes in vertical line; a vertical circular planing machine having a revolving table, on which the top and bottom edges of the rings of the shell plates are turned simultaneously; and the same tool is also capable of planing the horizontal seams; a boiler-end turning and boring machine for cutting out oval manholes; a machine for drilling bracket-holes; and a massive shaping machine, on which the corners of the plates are thinned, in order to avoid local heating. The electric-lighting plant, consisting of a dynamo machine driven by a semi-portable engine, provides light for the whole of the works and offices. Other buildings comprise the paint stores, rivet stores, general stores for castings, and the stables.

The fitting shop is compactly arranged, and well equipped with large lathes, radial and other drills, and a variety of other tools. The upper floor in this building is used for storing various parts of boiler fittings. Important extensions are nearly completed, which consist of a large new boiler shop, 186 feet long by 50 feet wide, containing two 6-ton overhead travelling-cranes, heavy bending-rolls, a plate-edge planing machine, boiler-end turning machine, and other tools, all of which are driven by electricity. The 250 horse-power horizontal side-by-side compound engines by Messrs. Robey and Co. are situated in the new engine and dynamo house at the end of this shop, with a rope drive to the dynamo. There is also a new triple riveting tower with three hydraulic riveting machines, and accumulator with 12-inch ram and 20-foot stroke. Lancashire and other boilers of large size, weighing 33 tons and more, and for pressures up to 200 lbs. per square inch, are the special production of these works. The number of men employed is about 400.

MESSRS. JOHN DEWSBURY AND SON, BRIDLE-BIT AND NICKEL PLATING WORKS, WALSALL.

These works were founded by the late Mr. John Dewsbury in 1840 in Duncalf Street, Walsall, and the increasing business was soon afterwards removed to Littleton Street. Here bridle-bits are produced in all qualities, sizes, and patterns; among the novelties are bits made with india-rubber mouthpieces for tender-mouthed horses, the chains inside being tested to stand a pull of 500 lbs.;

and medicine drenching bits, by which medicine may be easily given to horses and cows. Besides the usual japanned, tinned, and nickel-plated goods, bits in solid nickel silver are extensively made. In the new nickel-plating process steel articles are placed in a perforated cage, through which runs a brass rod connected electrically by its bearings with the rods that suspend it; the cage is spun in the green solution of nickel, and as the articles jolt about inside they take on the metal and polish themselves against one another. Some bits are cast, but most are forged; and skilful work is required to make the two halves of a light snaffle exactly alike. For making rings, a rod of steel is drawn from the forge, twisted round, run through a hole, welded, and moulded to shape with a few blows on a plug; the extra metal at the joint is removed by a file. The first polishing takes place in revolving cans amid sand and water or emery and oil; the last is performed on calico wheels with tripoli rubbed on from the cake. An interesting process is the making of moulds from the drawings. A piece of lead is carved to resemble the drawing as nearly as possible, from which a mould is taken in sand, and a casting made; the latter is then carved until it truly represents the drawing, and is then moulded, and another casting taken from it, which becomes the lead pattern for future use. The number of workpeople employed is 100.

MESSRS. E. T. HOLDEN AND SON,
TANNERS, CURRIERS, AND JAPANNERS, WALSALL.

This firm is one of the largest in the kingdom for the production of leather, required for the manufacture of saddlery and harness, for upholstery, for coach building, and for other purposes. It was founded in 1819 by the late Mr. E. Holden, whose son is the present senior partner.

The manufactory and warehouse are situated in Park Street, and are reached through a narrow passage adjoining the New Inns. What forty years ago were only one or two curriers' shops are now the largest works of the kind in Walsall; the latest additions are lofty five-storey buildings. They comprise offices, warehouses, depôts for hides in various stages of manufacture, including scouring shops with large scouring drum; compo houses, with ingenious mechanical appliances; splitting shops; finishing rooms; extensive drying sheds; rooms and sheds for polishing, for storage of oil, &c.; also blacksmiths' and carpenters' shops. Here are produced all kinds of enamelled and japanned leather, harness hides, legging hides, horse hides, leather for military belts, winkers, bridles, reins, stirrups, bags, braces, straps, and fancy articles. A branch of manufacture requiring most careful attention is that of hogskins for racing saddles, for which lightness is so important a consideration. The tan yard is in Beith, Scotland. The goods are sent from Walsall to London and the provinces, and also to the continent and the Colonies.

MESSRS. JOHN LECKIE AND CO., SADDLERY AND HARNESS WORKS, WALSALL.

Walsall is chiefly noted as a saddlery town, and has become the centre of this industry. The export manufacturing business of this firm, founded nearly fifty years ago, was transferred from Glasgow to Walsall about twenty-five years ago. It had been in existence for many years in Scotland, where a large manufacturing business for foreign and colonial trade was carried on; but owing to the facilities for obtaining materials, machinery, and labour in Walsall, it was found more profitable to transfer the industry from Scotland. They are the largest manufacturers in the various branches of the Walsall leather industry, ladies' saddles, hunting saddles, harness, army equipments, belts, strapping, purses, and every kind of equestrian requirements for foreign and colonial travel, which are all classified and worked under different departments. The firm manufacture their own leather; and the hides after being tanned are put through different interesting processes before they become ready for use in different colours, textures, and strengths. In the cutting room the leather is cut up by hand or by gauge-knives, or is placed under steam-power cutting-presses to be cut out into certain shapes, until gradually the articles get their final finish. The work is prepared for stitching by men and women; the hand-stitching is done in one department by girls and women, whilst the plain stitching in most cases is done in the steam-power machine-rooms, where there are about thirty machines, of all strengths and makes, both English and American, continually stitching articles from the lightest to the heaviest. After the goods are stitched and inspected they are finished and sent down to the packing rooms, where they are laid aside under different order numbers until their respective orders are completed, when they again undergo an inspection, after which they are ready to be packed in cases and sent by rail to the different ports of shipment. Among some of the articles produced here are bandoliers for South Africa, and eight-mule span-harness for the Transvaal, regular Cape harness for the Colonies, single harness for the East Indies and Australia, and mule harness for the West Indian plantations; whilst in the saddlery workrooms saddles are made of all styles, for almost every foreign market and for the Colonies, especially South Africa. In addition, some singularly built saddles have been made for South America, with the elevated Somerset cantles and thigh-pads, as well as some high knee-padded saddles for Australia. For the Kaffirs of the goldfields and elsewhere hundreds of grosses of money-belts have been made for their arms, wrists, and waists. A large amount of work is done for the government, especially for India and South Africa. The number of workpeople employed is about 300.

MESSRS. JOHN RUSSELL AND CO., ALMA TUBE WORKS AND CYCLOPS IRON WORKS, WALSALL.

This firm was established in 1811, and was the first to manufacture gas tubes by the drawing process. The Alma Tube

Works were commenced in 1854, and are now divided into three departments, employing altogether about 800 hands. The oldest department is the butt-weld mill, where butt-welded tubes, chiefly for high-pressure hot-water, heating, and hydraulic purposes, are made by the drawing process. Here also are made taper telegraph and tramway poles; railway point and signal rods; glass-blowers' tubes, &c. The ordinary butt-welded steam, water, and gas tubes are made at the Wednesbury works, and the process is similar to that employed in this department. There are also fitting and socket-makers' shops and a stamping shop, for making large sockets and flanges. Attached to this department also is the coil-shop, where coils of all sorts are made for heating and refrigerating, and tuyere-coils for blast-furnaces. In the lap-weld department, the mill consists of five welding and two skelping furnaces, five out of the seven being Siemens regenerative furnaces, supplied with gas from a range of Wilson producers; from these furnaces, tubes from 1½ inch to 18 inches diameter can be welded. The finishing shops are fitted up with tools for cutting off, screwing, staving, bulging, flanging, and other methods of making joints, either for fixing in boilers or for coupling together. Large quantities of oil line-pipe, well-boring and casing tubes, both for oil and water wells, are manufactured here, as well as high-pressure steam mains, iron and steel boiler and stay tubes, &c. Storage heaters for railway carriages and tramcars are also made, and sent out ready for fixing. The weldless-tube department, which has been recently added, is equipped with seven double draw-benches, five for cold-drawing tubes up to 2 inches diameter, and two powerful benches for drawing Belleville boiler-tubes and tubes up to 6 inches diameter for hydraulic purposes. The rolling mill consists of four pairs of rolls, driven by a tandem compound surface-condensing engine.

The Cyclops Iron Works employ about 400 hands, and can turn out 400 to 500 tons of finished iron per week, consisting chiefly of tube-strip iron for consumption in the tube works. There are thirty-two puddling furnaces, two of them working with forced draught, and the others of the ordinary kind. Three steam-hammers and a forge train with three pairs of rolls deal with the product of these furnaces. On the mill side are a 16-inch and 9-inch mill, both three-high. The 16-inch mill is engaged almost exclusively on rolling tube-strip from 4¾ to 15⅛ inches wide. The 9-inch mill rolls 4¾ inches and narrower strip iron, as well as bar iron. The heating furnace for the 16-inch mill is one of the new form of Siemens furnaces, and a second of the same kind is in course of construction.

MESSRS. JOHN SHANNON AND SON, CLOTHING AND WOOLLEN WAREHOUSE, WALSALL.

This establishment was founded by the father of the present managing director in the early part of the century as a drapery business, and was removed to the present site in George Street in 1845. In 1875 the drapery business was given up, and the manufacture of clothing exclusively undertaken. Owing to the great increase in the business, the original factory was demolished in 1894, and the present extensive buildings were erected in its place. Apparatus for making gas on the Dowson plan, and the necessary boilers, engines, electric-lighting machinery, and motors for driving sewing-machines, were designed by Messrs. Lea and Thornbery, of Birmingham.

The warehouse consists of two large blocks, covering half of one side of George Street. Every class of goods required in the manufacture of clothing is received in the basement, which extends the whole length of the building, about 250 feet. There are two woollen departments, one devoted to the ready-made woollen goods, and the other to clothing made to special measure. , The second floor is set apart for woollens and trimmings; and for offices, where all the cost pricing is worked out, and the clerical business is transacted. The trimming department comprises linings, braids, buttons, cottons, silks, and twists, &c. From the special-measure despatch-room about 4,000 garments are sent out per week, each of which has to be cut according to measures taken. The ready-made stock-room of the men's department contains a large assortment of garments, including worsteds, serges, and fancy suits. The despatching room is 180 feet long by 40 feet wide, and is fitted with tiers of shelves reaching to the ceiling. The matching room receives the garments from the finishing department, to be matched and made up into suits prior to their removal to the various stock-rooms. In the cutting room, where about 120 men are engaged cutting out, fitting, and trimming, are several machines with endless band-knives, any one of which is capable of cutting out from fifty to a hundred thicknesses of cloth at once, the top surface only having the pattern chalked upon it. The knives are driven by an electric motor, and the machines are supplied by Messrs. Beecroft and Co., Leeds. In the centre of the room is an office, in which all the patterns for special measures and stock are cut and stored, to the number of no less than 300 sets; and duplicates are deposited in the strong room in case of fire.

The new factory is a building of five storeys and basement, 150 feet long and 54 feet wide, and containing 50,000 square feet of floor area. The juvenile machine-room has accommodation for 400 work-people, and is capable of turning out 10,000 garments per week. It is fitted with Singer's sectional benches driven by electric motors, and contains a number of Barran pressing machines heated by Dowson gas, and worked by girls; also machines for sewing on buttons, each capable of attaching 10,000 buttons per week. In the department for making up men's clothing are Singer over-seaming machines for binding garments. The finishing room in the bottom storey is lighted by 20 arc-lamps, and can accommodate 500 girls. Before the erection of the new factory, the finishing work was done by outside labour. A large number of Reece button-hole machines are here employed, in which an indicator registers the number of stitches made; each machine can make 300 dozen button-holes a day, whereas a good day's hand labour would not produce more than ten dozen button-holes. In the serving room on Saturdays the bulk of the trimmings required for the following week are distributed. The pressing department, with accommodation for sixty men, is specially constructed on the shed principle, with a glass and tile roof supported by columns and girders; the heating stoves are separated from the rest of the room by a brick partition, and all fumes are carried off by two Blackman air-propellers, driven by electric motors. A large mess-room in the basement contains heating apparatus, in which food can be warmed.

The warming and ventilation of the building on the plenum plan has been carried out by Mr. W. Key, of Glasgow. The external air is drawn through a series of moistened screens, by which it is filtered. It then passes, when warmth is required, through a series of pipes filled with exhaust steam; and is forced through the building by a fan 10 feet diameter, driven by one of Messrs. G. E. Belliss and Co.'s compound inverted engines of 12 horse-power. The air in the building is changed seven times every hour in winter, and ten times in summer, the volume dealt with in summer being 4½ million cubic feet per hour. Ample precautions have been taken against fire by the provision of 657 Grinnell sprinklers, arranged by Messrs. Dowson, Taylor, and Co. The sprinkler itself is simply a small valve securely closed by a fusible solder joint, which melts at a temperature of 155° Fahr. They are distributed at equal distances in every room, and fixed close to the ceiling, so that in case of fire at any spot the water conveyed to each sprinkler by a pipe is automatically liberated, and discharged upon the fire exactly at the place where it has originated. Water can be obtained from either the town service main or a reserve tank of 6,000 gallons capacity placed on an elevated tower. For the lighting, warming, ventilation, and transmission of motive power, two steel Lancashire boilers, each 26 feet by 7½ feet, by Messrs. Edwin Danks and Co., of Oldbury, are fixed in a capacious boiler-house. The exposed portions of the boilers and pipes are covered with a non-conducting composition. Steam from the boilers is led by underground pipes to two turbine generators, made by Messrs. C. A. Parsons and Co., of Newcastle-on-Tyne, each large enough to drive 2,000 incandescent lamps of 16 candle-power. The electric motors were made by Messrs. Crompton and Co.; each drives two tables of sewing-machines. There are twenty-five motors for driving the sewing-machines, besides some larger for the cutting knives, &c.

The engine house contains a set of horizontal steam-pumps, made by Messrs. Tannett, Walker and Co., of Leeds, for pumping into an accumulator for working the three hydraulic lifts by Messrs. Waygood and Co. For heating the pressing-irons about 54,000 cubic feet of Dowson gas are used per day. Town gas is used for a 12 horse-power Crossley gas-engine, which drives a dynamo for supplying a small number of electric lights occasionally used.

DAIMLER MOTOR MILLS, COVENTRY.

The Daimler Motor Co., formed in March 1896, was the first company started in this country with the object of entering upon the manufacture of horseless carriages or autocars; and the factory today is the largest and best organized for this purpose in the country. The manufacture is not restricted to autocars, but Daimler motors are made both for the propulsion of launches, and also for use as stationary engines for driving small machinery. The present factory was acquired in May 1896, with the surrounding eleven acres of ground. The premises consist of two blocks of buildings at right angles to each other. Next to the manager's and clerks' offices comes the heavy machine-tool shop, measuring 172 feet long by 35 feet wide, and containing the heavier tools required for turning fly-wheels and heavy crank-shafts, planing gear-boxes and motor-frames, and similar heavy work. Above this is the brass-workers' shop, in which are manufactured all the brass and gun-metal fittings. At right angles to these shops are the principal machine-tool shop, 85 feet long by 56 feet wide, and the tool-makers' department; the former is filled with lathes, milling machines, and other tools of a lighter class than those in the first shop. Another workshop of the same size is devoted to the erection of completed motors, where the various parts are assembled together, and fitted into place. Adjoining on one side are the store rooms for finished goods, and on the other side a spacious and well arranged smiths' shop. Another workshop, like the smiths' shop, has recently been erected close by, in which the motors are tested and finally adjusted, until they are shown to be in proper working order and giving off the required horse-power.

Operations having already been hampered by want of room, a new workshop for the special purpose of the motor-carriage building department has just been completed on the other side of the railway line which runs through the works. This shop measures 120 feet long by 130 feet wide, and is being equipped with the necessary machinery for the manufacture of the different portions of the frame and gearing, and with a number of fitting benches and an erecting pit, for properly building up the complete autocars. The drawing office, pattern-makers' shops, stores for finished patterns, and tinsmiths' department, are upon an upper floor, whilst the painting and finishing of the completed articles is carried on in a separate building close by, abutting upon the private railway line on one side, and upon the canal on the other. Between 200 and 300 men are now employed, and for some time autocars have been delivered at the rate of about three per week; this number is expected to be largely increased when the new workshops are in full working order. In the hands of its continental manufacturers the Daimler motor has been used upon the winning carriages in all the chief continental road competitions, notably that held last year, when three carriages fitted with Daimler motors were entered, and finished first, second, and third, accomplishing the journey of over 1,000 miles, under most adverse circumstances as to wind and weather, at an average speed throughout of over 16 miles per hour. The size of motor upon which the works are principally engaged is the 4 horse-power; and this is so arranged that without alteration of the machinery it can be fitted either to light parcels-delivery vans, or to carriages of a number of different shapes for four to six persons. Other sizes also in hand are 2, 3, 6, and 10 horse-power. Every carriage on completion is put through a road test of at least 100 miles before being delivered to the purchaser.

MR. ALFRED HERBERT, MACHINE-TOOL WORKS, COVENTRY.

These works, which were established in 1887, are situated within a few minutes' walk of the station, and cover about 1½ acre. The various shops, which contain about 62,000 square feet of floor space, are arranged about a central yard, in which are situated the castings store, engine house, boiler, etc.

The machine shop is a one-storey building 165 feet long by 115 feet wide, having at one end a two-storey portion which contains the manager's office, drawing office, pattern shop, and pattern stores. Power is supplied to the machine shop by a compound vertical high-speed Robey engine, of 150 horse-power, and taking steam from a Babcock boiler. The lighting of this portion of the works is by incandescent gas burners arranged in groups, and hung on spiral coils of tube forming springs to protect the mantles from vibration. The shops are warmed by exhaust steam, and in very cold weather live steam can be turned into the heating pipes the first thing in the morning, so that the men start work in a warm shop. The machine shop is served by several overhead travelling-cranes; and a tramway connects it with the castings store and erecting shop. The machine-tools in use number about 180, and the various kinds are arranged as far as possible in groups, with a leading hand in charge of each group and responsible for the work produced. Owing to the constant increase in the number of machines employed, it becomes necessary periodically to re-arrange considerable portions of the plant, so as to retain the desired grouping; one of these periodical re-arrangements is in progress at the present time.

The turning bay contains the usual lathes, many of American make, and some of them having special attachment for special work. The number of capstan lathes which are grouped together at one end of the machine shop is considerably larger in proportion than is usual, because a large portion of the work usually turned from forgings on ordinary lathes is here produced from the bar on capstan lathes. Only one smith is employed, and his time is almost entirely occupied in tool dressing. The capstan lathes are supplied with pure lard oil in abundance from an overhead tank, to which the surplus oil is returned by a pump; and the turnings produced are spun in a centrifugal extractor, to avoid waste of oil. In the planing and milling bays a number of machines are at work, which represent modern practice in both of these lines. The universal grinding machine is used for finishing almost all cylindrical surfaces; and a considerable amount of flat work is finished on surface grinders of various sizes. Automatic gear-cutting and rack-cutting machines are also at work; no cast gears of any kind are used. A portion of the machine shop is set aside as stores for the reception and inspection of finished parts, and there is also a tool room with gas-hardening furnaces and the usual appliances. Adjoining the machine shop is the bar store, with cutting-off and centring machines for preparing the bars for the turners. Adjoining is the mess room with cooking and washing accommodation.

The fitting and erecting shop is 140 feet long by 125 feet wide. Besides being occupied by the fitters and erectors, it also contains drilling and polishing machines, and other tools needed in connection with fitting. Each line of shafting in this shop is driven by an electric motor, to which current is supplied by a Mavor and Coulson generator coupled direct to a Westinghouse compound engine. The electric light is in process of installation, and the heating is furnished by exhaust steam. The shop is well served by travelling cranes, and is provided with a tram line connecting with the machine shop and the stock room. Provision is here made for working, testing, and inspecting the finished machines. Across a small yard, used for the storage of packing cases &c., is a newly-erected three-storey block 135 feet long by 30 feet wide, of which the ground floor is to be used as a stock room; this is furnished with travelling crane and tramway, and an elevator serves the two upper floors, which will be used for manufacturing purposes, and will be driven and lighted by electricity.

The work turned out consists exclusively of machine-tools: comprising capstan lathes, of which a large number of kinds are built of various sizes; milling machines; sensitive and multiple drills; centring machines; lathes; polishing machinery; and a number of tools which have been specially developed in connection with the manufacture of cycles and other repetition work. The number of men employed is about 250. In addition to the tools manufactured, a considerable business is done in the importation of American machine-tools, of which stocks are kept both at Coventry and also at depôts of the firm in London and Birmingham, as well as a reserve at the docks.

Up to the present time castings have not been produced; but it has been found necessary to erect a foundry, and for this purpose a plot of two acres has been acquired, situated on the canal about two miles from the main works. The foundry now approaching completion is a steel structure 120 feet long by 80 feet wide, fitted with a five-ton electric travelling-crane, and lighted and driven by electricity throughout. Gun-metal and phosphor-bronze castings will also be made there. In addition there are pattern stores, stables, fettling shops, and stores, with facilities for the ready handling of the product.

TRIUMPH CYCLE WORKS, COVENTRY.

This business was started about seven years ago in Much Park Street; and owing to the rapid strides since made, requiring much larger premises, the present buildings in Priory Street were erected and completed last year, covering an area of more than 6,000 square yards. The offices and managing director's rooms in the front are lighted throughout by electricity, as are also some portions of the works.

Every part of the cycles here made is turned out on the premises from the raw materials; and automatic and labour-saving machinery is used as far as possible. Perhaps the most interesting tool in the works is the hub-forming machine, which takes in at one end a solid bar of mild steel $1\frac{3}{4}$ inch diameter, and delivers it at the other end with flanges and barrel ready for boring out. Every $3\frac{1}{2}$ minutes a hub is formed; and as these accumulate they are taken away in dozens to be countersunk in special jigs, so as to ensure perfect accuracy in the boring, which is then done easily by another special machine. The barrel is next threaded internally for the adjusting discs, and externally for the locking nut; and is then taken to a drilling machine, which almost automatically bores the spoke-holes, so that one hub is a facsimile of another. This principle of duplication by special machinery holds good throughout the many parts of which the cycles are composed. Frame setters, working with steel gauges for the angles and distances, pass each frame carefully through a determined series of tests before the next portion is built up. The frames are next subjected to the sand-blast, by men who work in helmets similar to those used by divers, in a room almost air-tight, while the sand jet plays on the joints to remove the surplus brazing. Thence the frames go to the buffing and polishing shop, the enamelling ovens, the plating shop, and finally the packing shop. These cycles have been awarded four gold medals and numerous diplomas of honour at various international exhibitions. Fire hydrants are fitted up throughout the whole of the building, and an efficient fire brigade has been formed of men employed in the works, of whom there are at present from 500 to 600. Over 500 machines are often turned out per week. This firm made the two cycles which the Mayor of Coventry presented to the Queen upon the occasion of the Diamond Jubilee.

HUMBER CYCLE WORKS, COVENTRY.

In consequence of the old works of the Humber Company in Coventry having been destroyed by fire on 17th July 1896, the present factory of four times the size was erected and equipped on the same site, under the management of Mr. Walter Phillips, who had previously been for fourteen years manager of the Rudge Cycle Works, Coventry. The old works gave employment to over 700 men, and had been under his management since 1893, although the Coventry branch was in existence as far back as 1886. The new factory is capable of producing 1,000 machines a week, necessitating the employment of 1,300 men, for whose accommodation no less than 5,000 feet of benching and 800 fixed vices are required, while the remainder of the men are engaged in the machine shops, smithy, enamelling, plating, polishing, and packing shops. The factory consists of four storeys, containing an aggregate floor area of 80,000 square feet. The offices and stores have a frontage extending along Lower Ford Street and Hood Street, with a spacious entrance at the corner; and are fitted throughout with complete telephonic communication, electric lighting, and steam radiators for warming.

In the machine shop on the ground floor are special machines for forming axles from the solid bar. Beyond is the cone-making machinery, and farther on a group of milling and profiling machines for the various operations in the production of cycle parts. A large bay extending 100 feet to the main engine-house is almost filled with capstan lathes, and a number of automatic machines for the manufacture of cups and cones. The polishing or glazing shop adjoining contains 100 double spindles, at which 200 men are engaged in grinding and polishing up the frames and other parts preparatory to enamelling. The area of this shop is 3,000 square feet, and the machinery is driven by a high-pressure condensing engine of 25 horse-power at the end of the shop. The main engine-house contains a high-pressure condensing engine of 50 horse-power, provided with steam by two Galloway boilers; the engine and boilers are practically the sole survivors of the fire. On the other side of the lathe bay is the plating shop of 1,500 square feet area, containing nine large plating vats, as well as a number of scrubbing and washing baths. It is supplied with current by two dynamos, each having an output of 300 ampères.

The extension building is crowded with machinery similar to that in the old portion, and contains in addition a set of hub-making machines and other labour-saving devices. The hub-making machines form a complete hub out of the solid bar. The whole of this machinery is driven by a 35 horse-power Crossley gas engine.

which is contained in the engine house at the end of the shop. The floor area of the whole of the machine shop is about 20,000 square feet, and contains 250 machine-tools.

The smithy, built in a square courtyard, is one storey high, with glass roof and ventilators, and four chimneys, one on each side. It covers 2,000 square feet, and is entirely separated from the main building. It contains ten fires, for which the blast is provided by a Root's blower outside ; also a steam hammer, and all the appliances for manipulating tubes and the various forgings required in the manufacture of cycles.

On the first floor is the enamelling shop, containing 25 large glazed-brick stoves, in each of which 100 cycle frames can be put at one time. A smaller shop is partitioned off for the special colouring and lining of machines. The whole shop has a floor area of 3,000 square feet, and is ventilated by a Blackman fan. Beyond is the wheelmaking shop ; and then the erecting or assembling department, followed by the fork-building, handle-bar, and brake-work fitting shop, adjoining the finishing departments. In the middle of this floor is the chief engineer's office, and also the drawing office, in which the designing of bicycles and the study of methods of manufacture are carried on.

On the second floor is the frame-building department, in which 400 men are employed on frame-building alone ; there are also large brazing shops, which are separate from the main shop. The bay over the wheel-making shops is reserved for filing the joints and lugs of the frames after they are built and brazed. The frame-trueing and sand-blasting shops are over the enamelling shop. The sand-blasting process precedes the filing up ; the blast is furnished by a blower driven from the main shafting. The carpenters' and pattern-makers' shops are on the third floor. The main portion of this floor is reserved for a stock room, for which at present there is not much use. In the old courtyard is a case-hardening apparatus, situated at the end of the boiler house ; also an underground heating-chamber, from which pipes are laid for warming the whole building ; and the electric-light engine-house.

NEW PREMIER CYCLE WORKS, COVENTRY.

This firm was established by Messrs. Hillman and Herbert in 1875, the senior partner having been previously associated with the late Mr. James Starley since 1869 in the manufacture of sewing machines and bicycles. The bicycle made was the well-known "Premier," until the first geared-up small bicycle, the "Kangaroo," was evolved by the ingenuity of Mr. Hillman, which at once led to a large increase of business. In 1886 the firm was formed into a private company; and three years after a factory was established near Nuremberg in Bavaria, and later another factory at Eger in Bohemia.

The Coventry works cover an area of some acres, with frontages in Read Street and South Street of 300 and 200 feet respectively. On each side of the main entrance in Read Street are the suites of offices, beyond which is a lofty stock room, 80 feet square, capable of storing upwards of 6,000 cycles. Then follow show rooms, and in the basement the india-rubber tyre department, with additional space for reserve stock. An annexe, 150 feet long by 20 feet wide, with glass roof, leads to the photographic studio. The building shop, 180 feet long by 80 feet wide and lighted by roof lights, contains all kinds of modern tools and appliances for erecting cycles, including lathes, drilling, shaping, planing, and turning machines, surrounded and intersected by numerous benches. On one wall hang several hundred finished cranks, arranged in rows ready for attachment to their spindles; on another is a collection of front forks with steering posts; one bench is covered with handle-bars complete; another with detachable cranks, under which stands a row of enamelled mud-guards made up with stays. On the roof-beams are suspended rows of wheels, frames, forks, and other parts. In making the back hub thirty-six distinct machining operations are effected, without taking into account the making of the balls, or the various plating or polishing processes; a bottom bearing bracket requires thirteen complete processes on the shell alone, and a crank sixteen.

Much attention has here been devoted to the improvement of the tube forming the frame-work of the machine, which in the majority of other makes of cycles is composed of solid-drawn tube of mild steel. After a series of experiments a helical tube was introduced a short time ago, made of a thin strip of steel rolled or twisted helically. The material for the tubes comes from Sweden, and arrives in the form of bright sheet steel, from 0·008 to 0·017 inch thick, and varying in width according to the diameter of tube required. It is formed into tubes in special machines, which fold the steel round mandrils with great tension, and in this condition it is brazed. The brazing has been brought to such perfection that between the two layers of steel a perfect film of brass is interposed, so that the finished tube really consists of three thicknesses. Up to the present $1\frac{5}{8}$ inch is the largest diameter made of helical tube, and $\frac{3}{8}$ inch the smallest. All parts of the bicycle frames are made of this helical tube, except the handle-bars which are curved, and the fork sides which are oval in section.

The list of awards gained by these works includes three medals for bicycles, tricycles, and helical tube at the Chicago Exposition. The number of men here employed amounts to about 600; and some hundreds are employed at the works on the continent and the various warehouses and repairing branches in all parts of the country.

MESSRS. JOSHUA PERKINS AND SONS, BRITANNIA WEAVING MILL, COVENTRY.

This business of manufacturing coach trimmings was established by the senior partner half-a-century ago at Lubenham, near Market Harborough, and in 1865 was removed to Coventry. The premises now occupied in Payne's Lane were erected eighteen years ago. The front elevation, extending a width of 140 feet, is of three storeys, surmounted by a large stone figure of Britannia, furnishing a prominent landmark for the neighbourhood. The front portion is principally occupied as private and general offices, warehouse and stock-rooms, flanked at either extremity by wide cartway entrances for goods. The weaving sheds, extending 200 feet to the rear, are lofty, well built, and well lighted. The works are fitted throughout with machinery of the most modern kind, comprising about 150 looms, which are driven by a powerful engine and boilers, situated in a separate building on the ground. The work produced comprises every description of carriage trimmings and upholstering requisites, which are largely supplied to the principal railways, wholesale coachbuilders' warehousemen, and shippers. About 200 workpeople are employed, both on the premises and outside.

MESSRS. WILLANS AND ROBINSON, VICTORIA WORKS, RUGBY.

These new works have been constructed for the manufacture of the Willans central-valve engine, and of the Niclausse water-tube boiler. They are still partly unfinished, but the machine shop has been in operation since March last, and some other shops have been got to work since. Work continues to be carried on in the old works at Thames Ditton, where the lighter standard parts are made to gauge, and forwarded to Rugby for examination and use. The area covered by the works, yards, and open spaces is about 11 acres, and there remain 12 acres for future extensions. The roofs of the shops are constructed on the weaving-shed plan, with a northern light. The buildings are for the most part arranged side by side, facing the railway, with passage ways between. The largest building includes the machine shop, the general and manufactured stores, and the erecting shop, and has a frontage of 300 feet; at present it is 160 feet deep, but is now being enlarged so as to be 240 feet in depth. There is a boiler shop, unfinished, measuring 150 feet frontage by 100 feet depth; and foundations are in place for an extension to double the size. The foundry main building at present covers a space of 200 feet depth by 80 feet frontage; and there are separate buildings for pattern shop, packing shop, pattern stores, &c., as well as for the general and drawing offices. The building for the testing department is next the general offices, and covers 110 feet by

100 feet. There is a tower for a tank containing 80 tons of water, connected to fire mains laid to all the buildings. A men's mess room, combined with lavatories and bicycle stable, is being built. The tools in the machine shop are principally lathes, and there is a special milling machine of somewhat new design. Electrical travellers are largely employed, and a considerable number of electric motors are used for other purposes. The number of men already employed is about 300.

Institution of Mechanical Engineers.
Record of Progress from commencement.

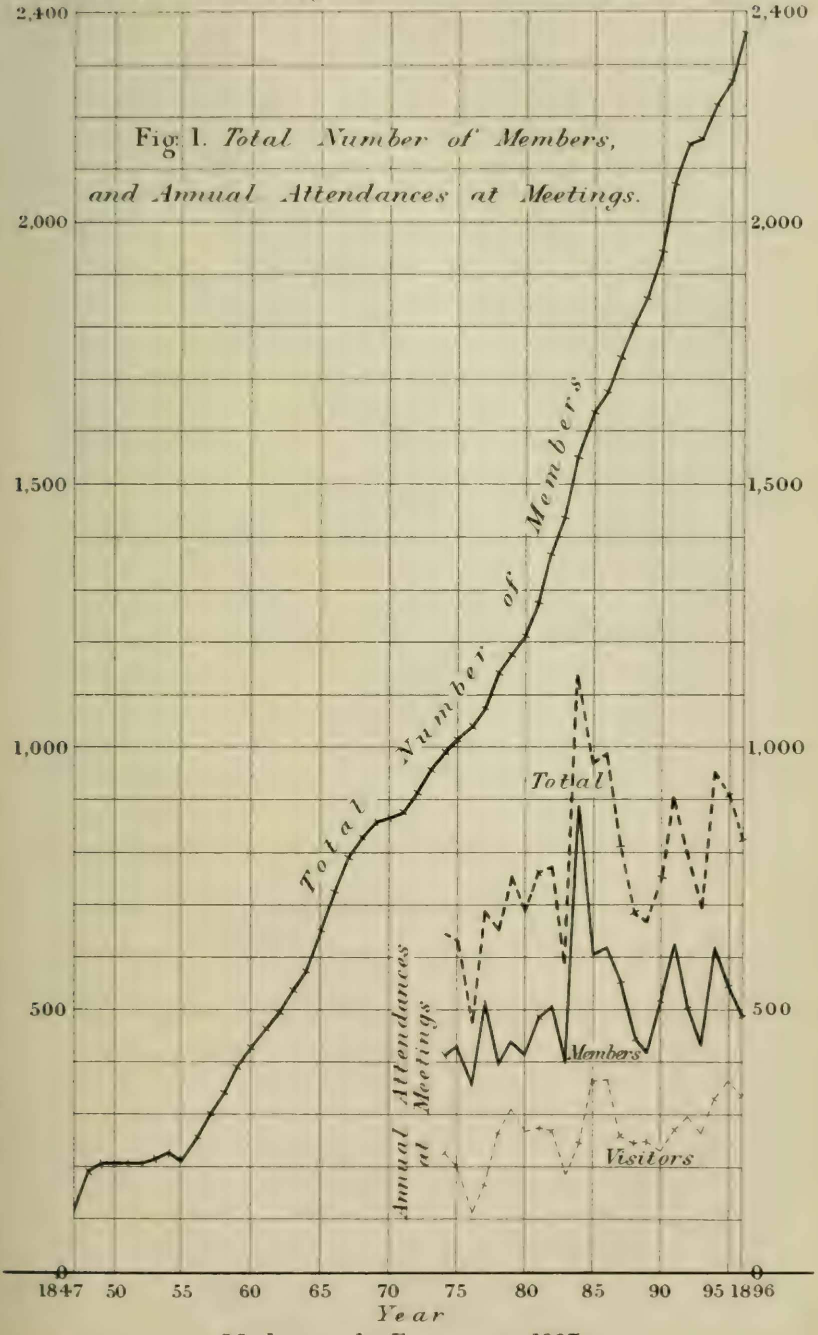


Fig. 1. *Total Number of Members, and Annual Attendances at Meetings.*

Institution of Mechanical Engineers.
Record of Progress from commencement.

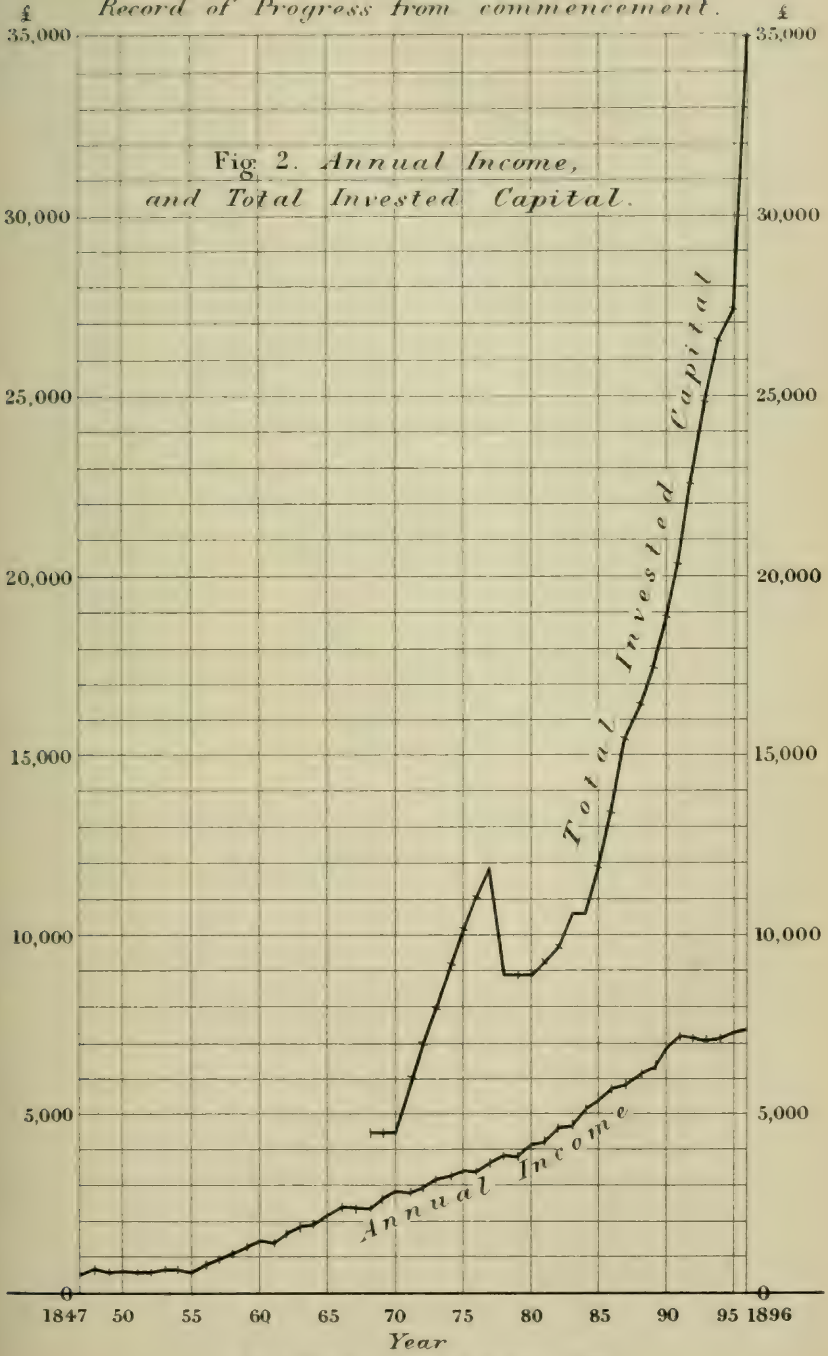


Fig. 2. *Annual Income, and Total Invested Capital.*

CYCLE CONSTRUCTION.

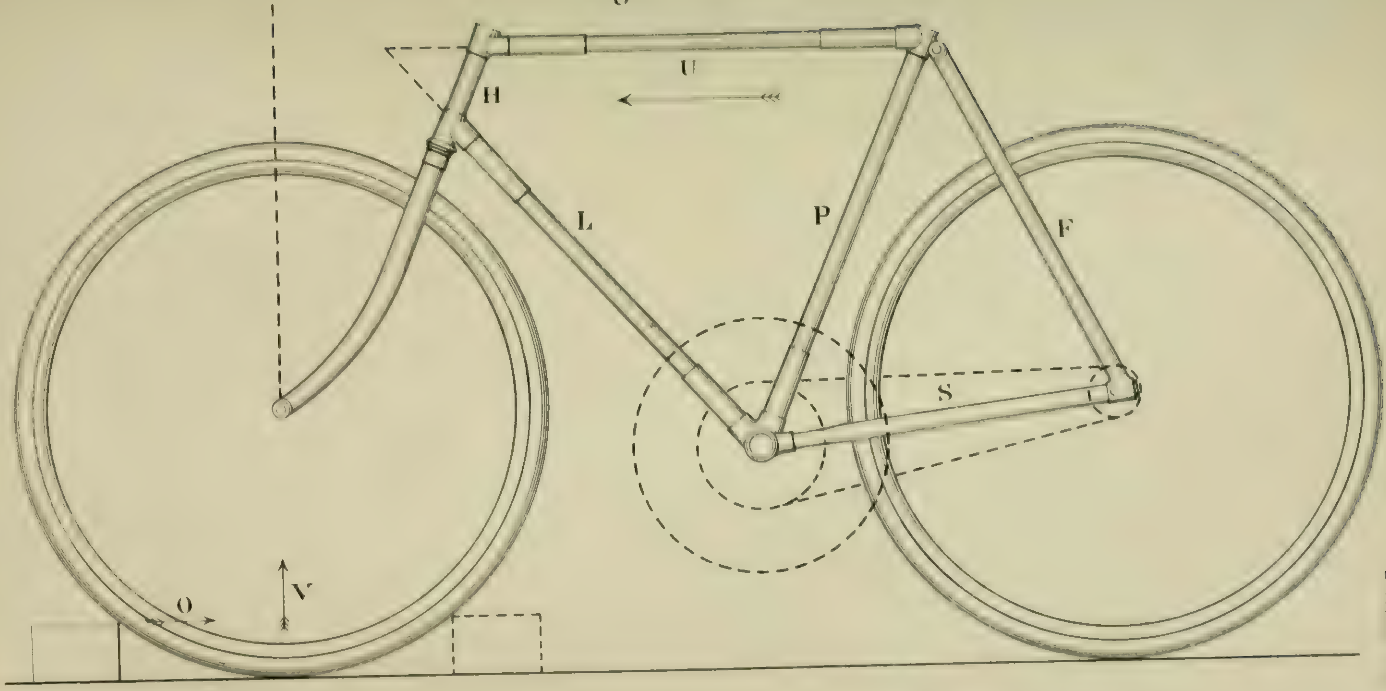


Fig: 1. *Frame.*

Scale 1/10th.

Mechanical Engineers 1897.

Plate 48.

CYCLE CONSTRUCTION.

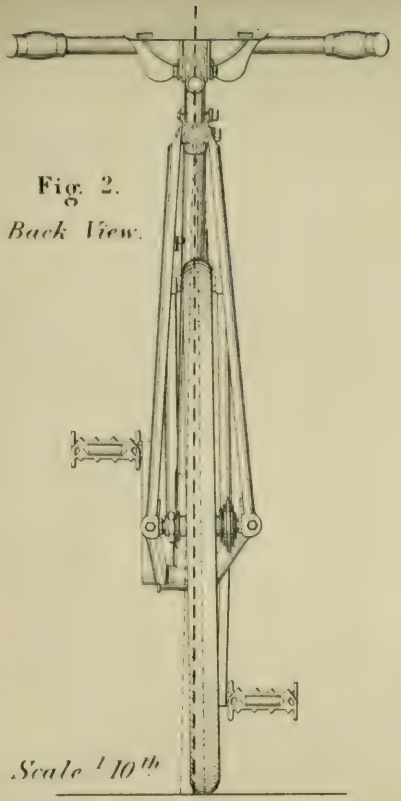
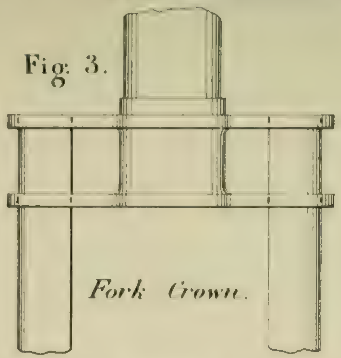


Fig. 2.
Back View.

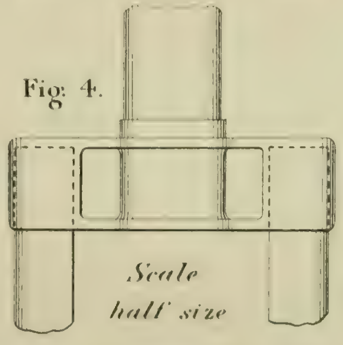
Scale 1/10th.

Fig. 3.



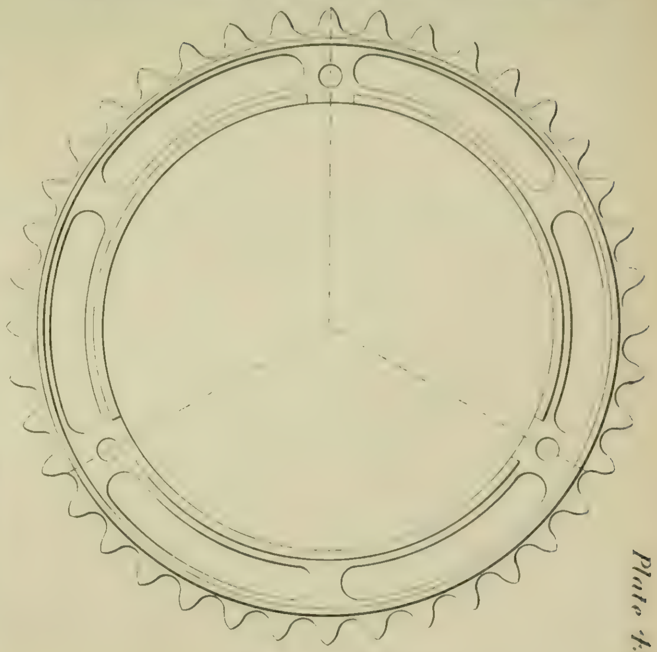
Fork Crown.

Fig. 4.



Scale half size

Fig. 5. *Chain Wheel of half-inch pitch.*



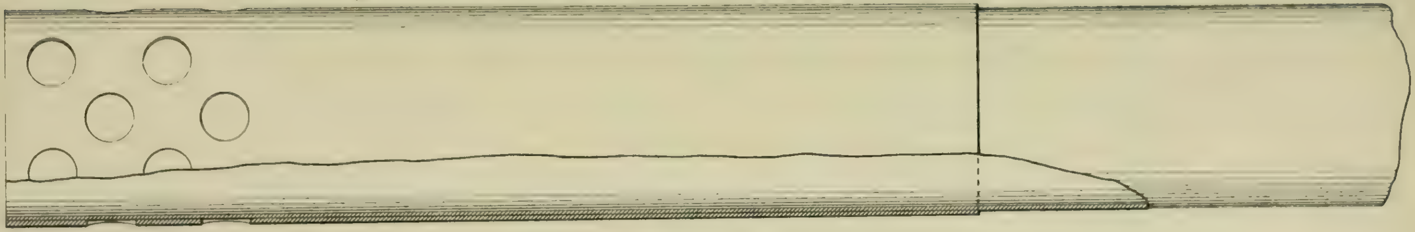
Scale half size.

Mechanical Engineers 1897.

CYCLE CONSTRUCTION.

Plate 50.

Fig. 6. *Reinforcement on Tube end. Full size.*



Corrugated Tube.

Fig. 7. *Longitudinal View.*

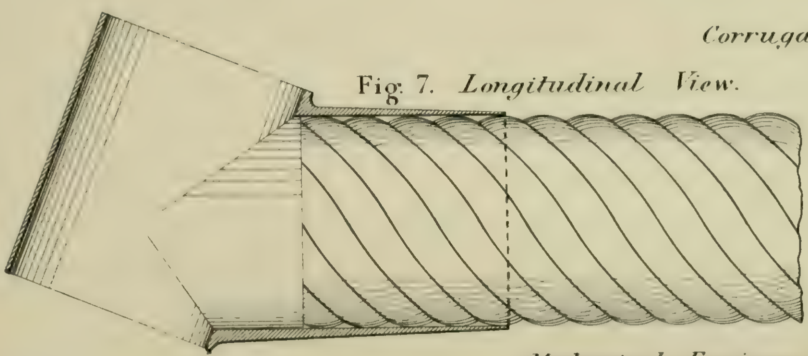
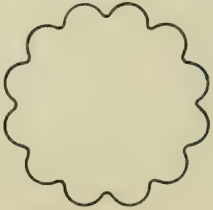


Fig. 8. *Transverse Section.*



Full size.

Mechanical Engineers 1897.

Plate 50.

CYCLE CONSTRUCTION.

Joints.

Fig. 9.

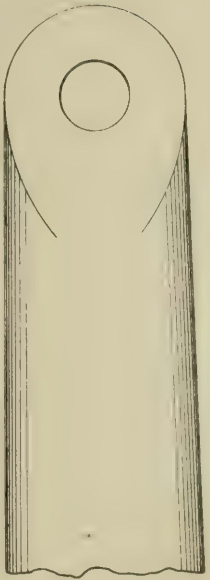


Fig. 10.

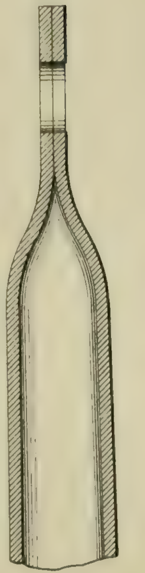


Fig. 11.

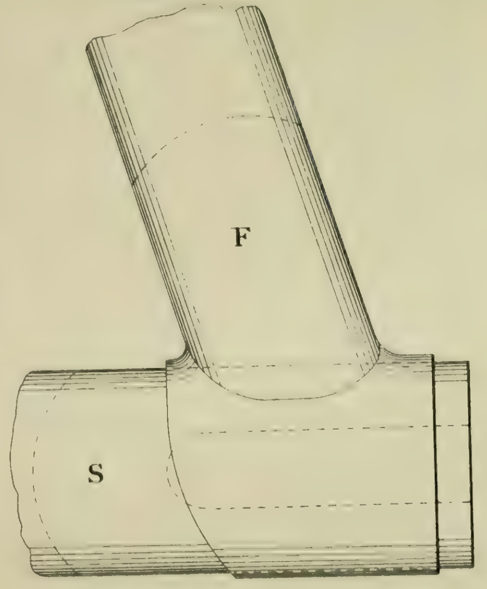


Fig. 12.

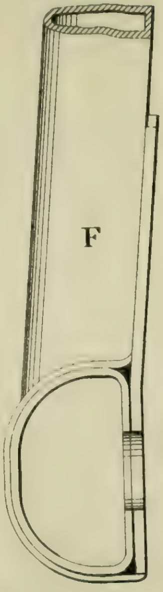


Fig. 13.

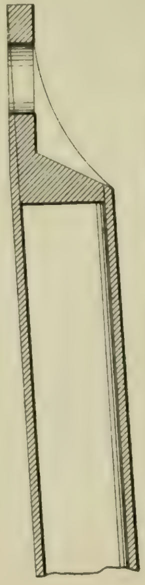
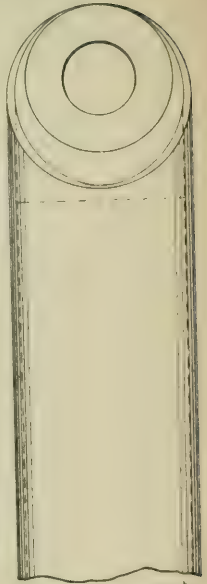


Fig. 14.



Full size.

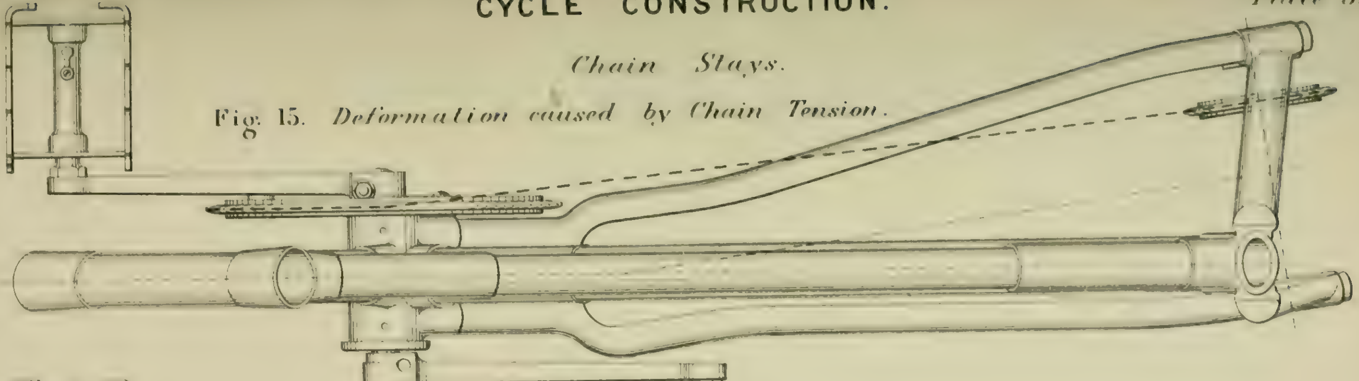
Mechanical Engineers 1897.

Pl. 51.

CYCLE CONSTRUCTION.

Chain Stays.

Fig. 15. *Deformation caused by Chain Tension.*



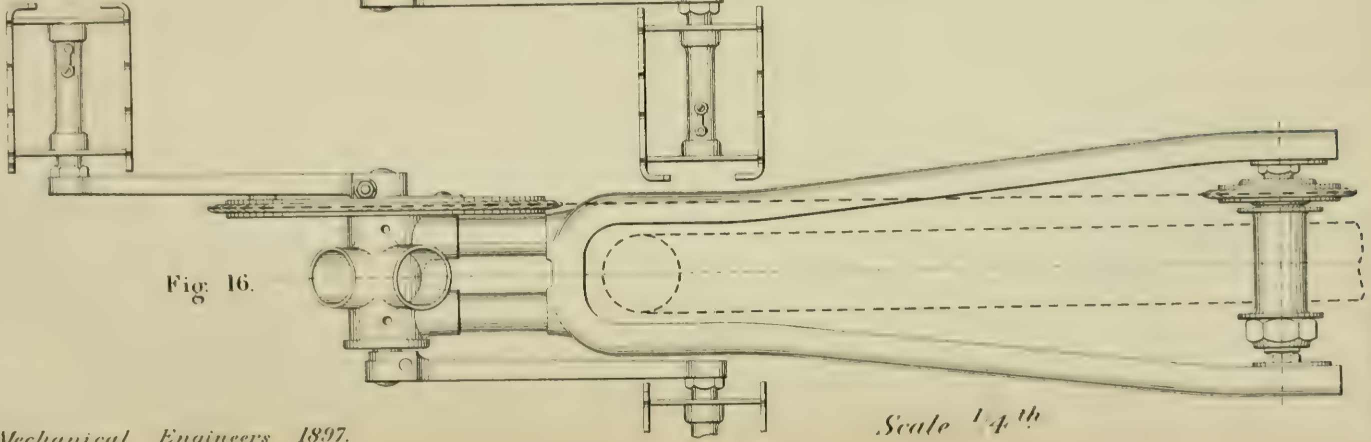


Fig. 16.

Scale $^{1}/_{4}{}^{th}$.

Plate 52.

CYCLE CONSTRUCTION.

Plate 53.

Chain Adjustment.

Fig: 17.

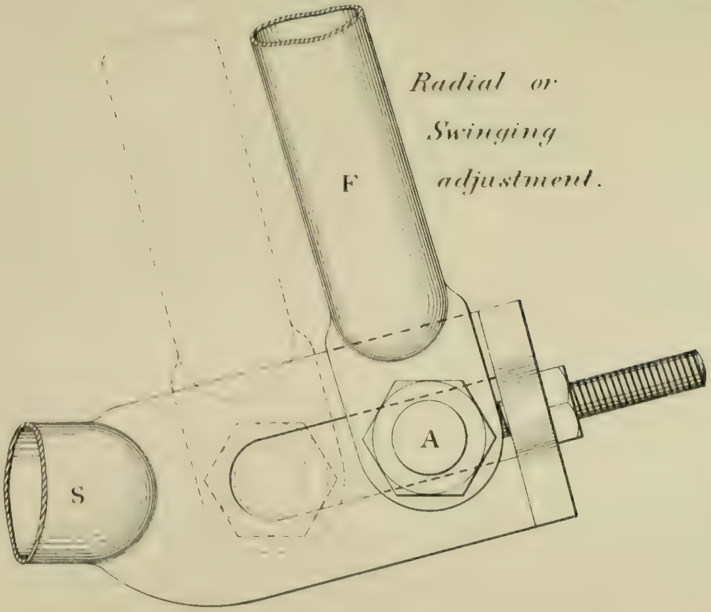


Fig: 18.

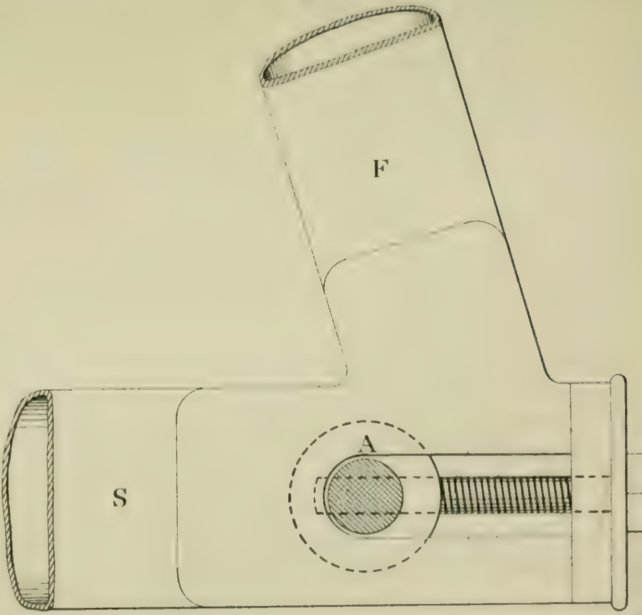


Plate 53.

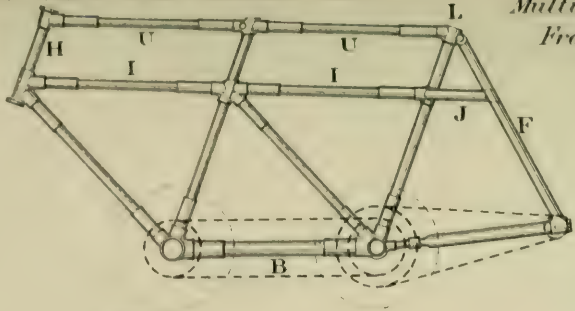
Full size.

Mechanical Engineers 1897.

CYCLE CONSTRUCTION.

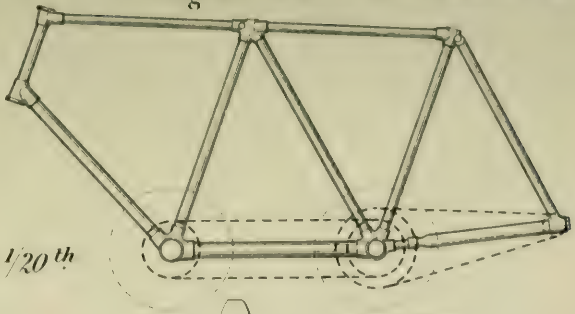
Plate 54.

Fig: 19. *With intermediate tube.*



Multicycle Frame.

Fig: 20. *Without intermediate tube.*



Scale 1/20th.

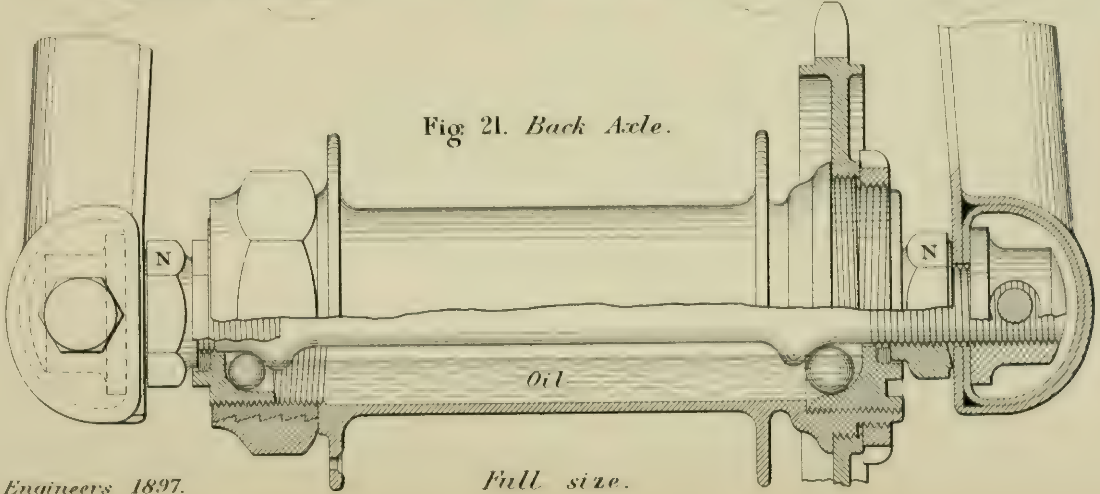


Fig: 21. *Back Axle.*

Full size.

Mechanical Engineers 1897.

CYCLE CONSTRUCTION.

Tube Sections.

Fig: 22.

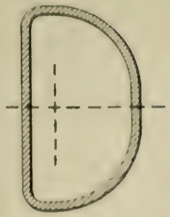


Fig: 23.

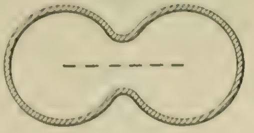


Fig: 24.

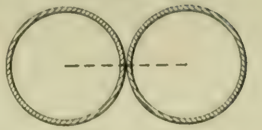
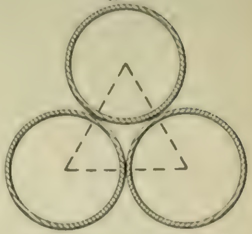


Fig: 25.



Full size.

Roller Chain.

Fig: 26. *Plan.*

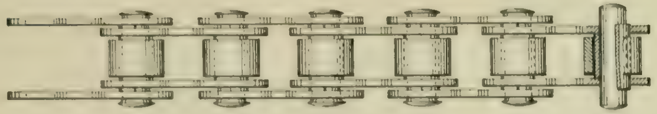
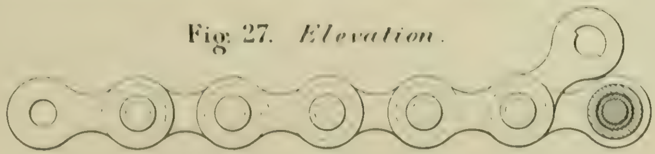


Fig: 27. *Elevation.*



Block Chain.

Fig: 28. *Plan.*

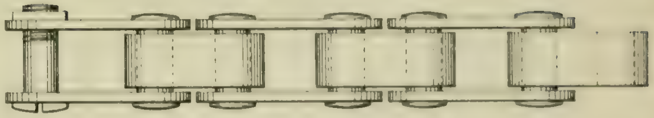
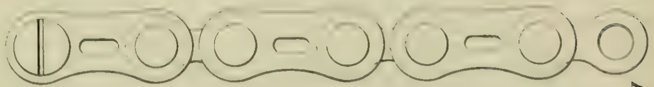


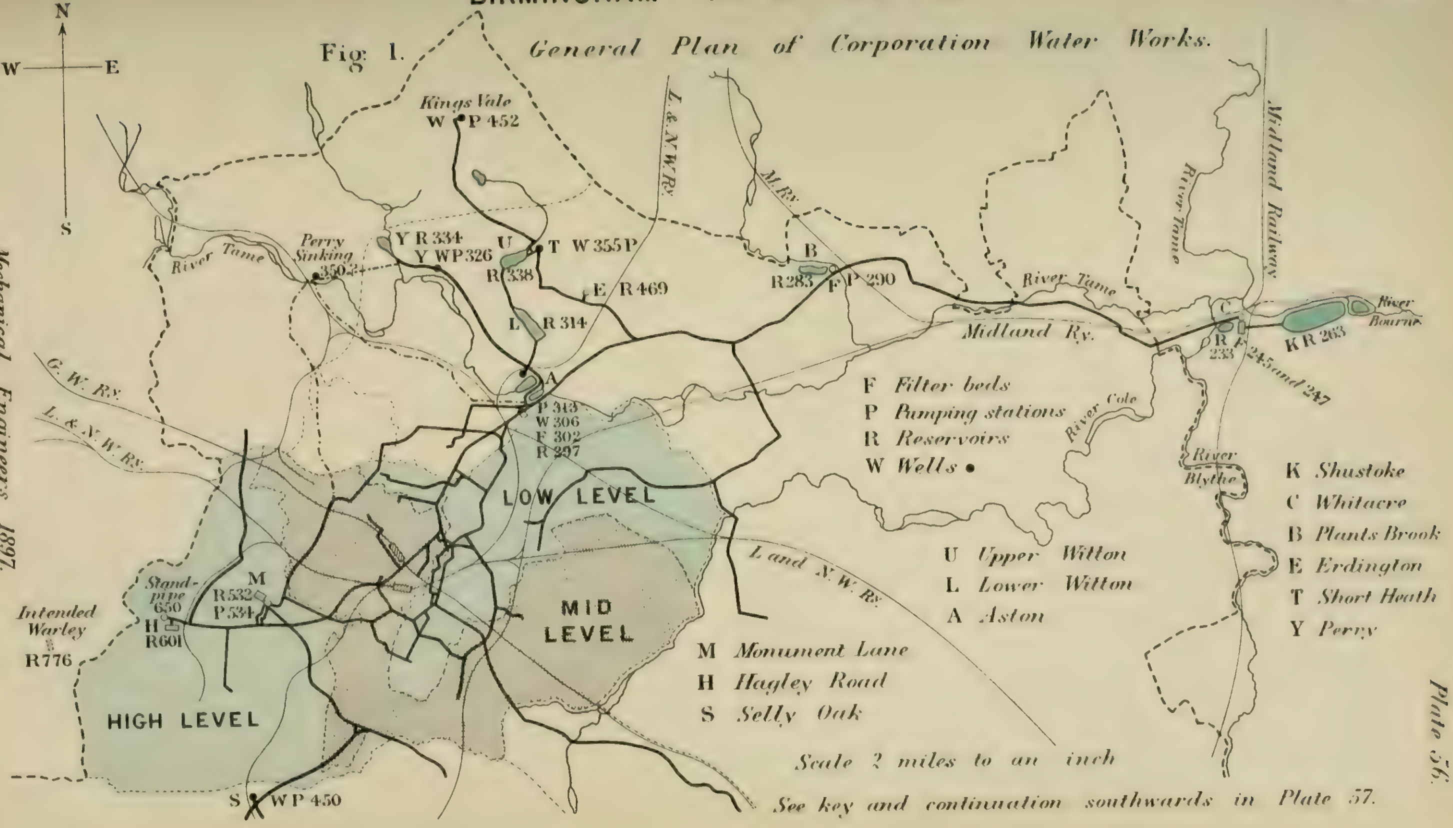
Fig: 29. *Elevation.*



Full size.

BIRMINGHAM WATER WORKS.

Fig. 1. *General Plan of Corporation Water Works.*



Scale 2 miles to an inch

See key and continuation southwards in Plate 57.

Plate 56.

BIRMINGHAM WATER WORKS.

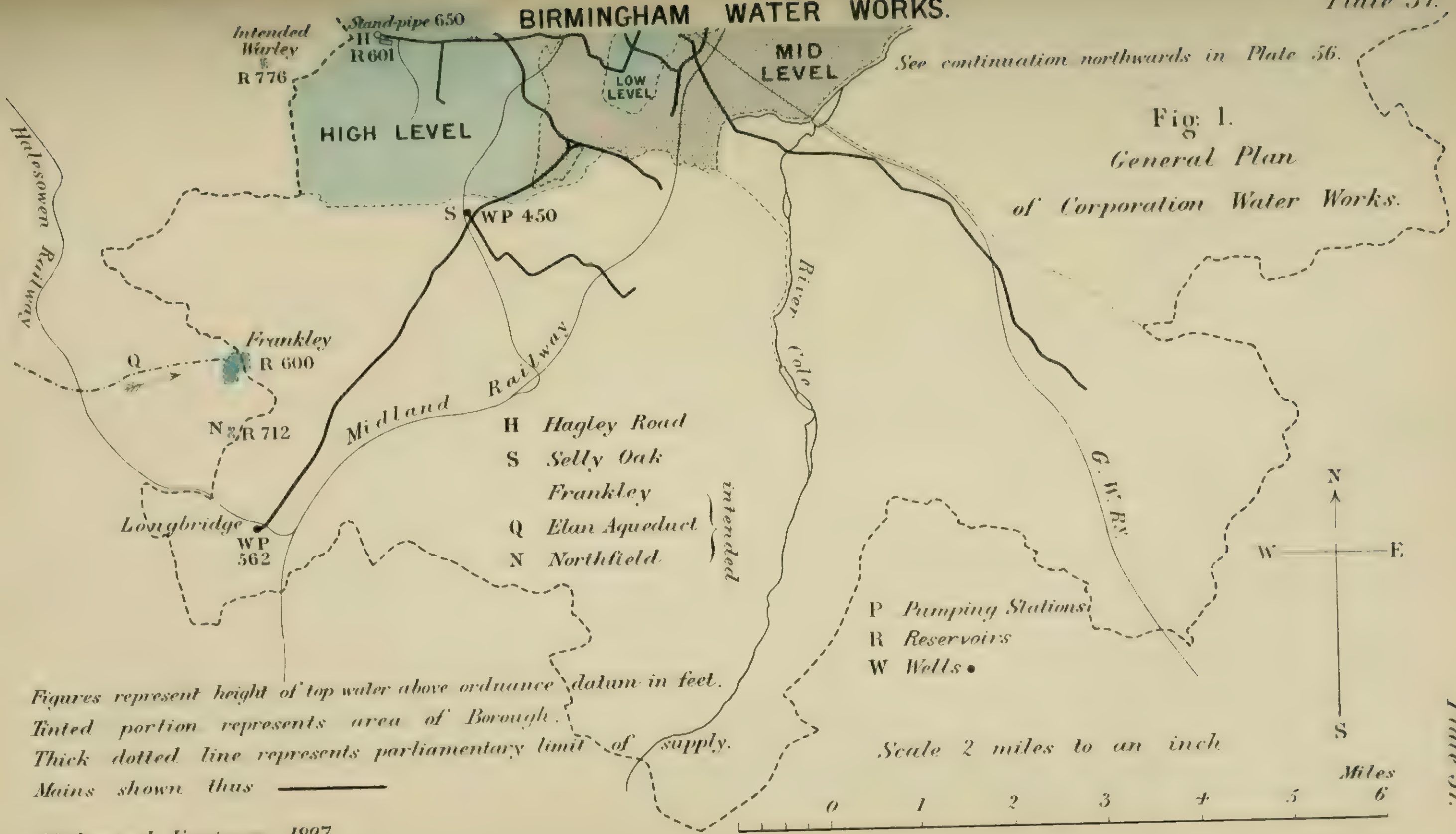


Fig: 1.
General Plan
of Corporation Water Works.

Figures represent height of top water above ordnance datum in feet.
Tinted portion represents area of Borough.
Thick dotted line represents parliamentary limit of supply.
Mains shown thus ———

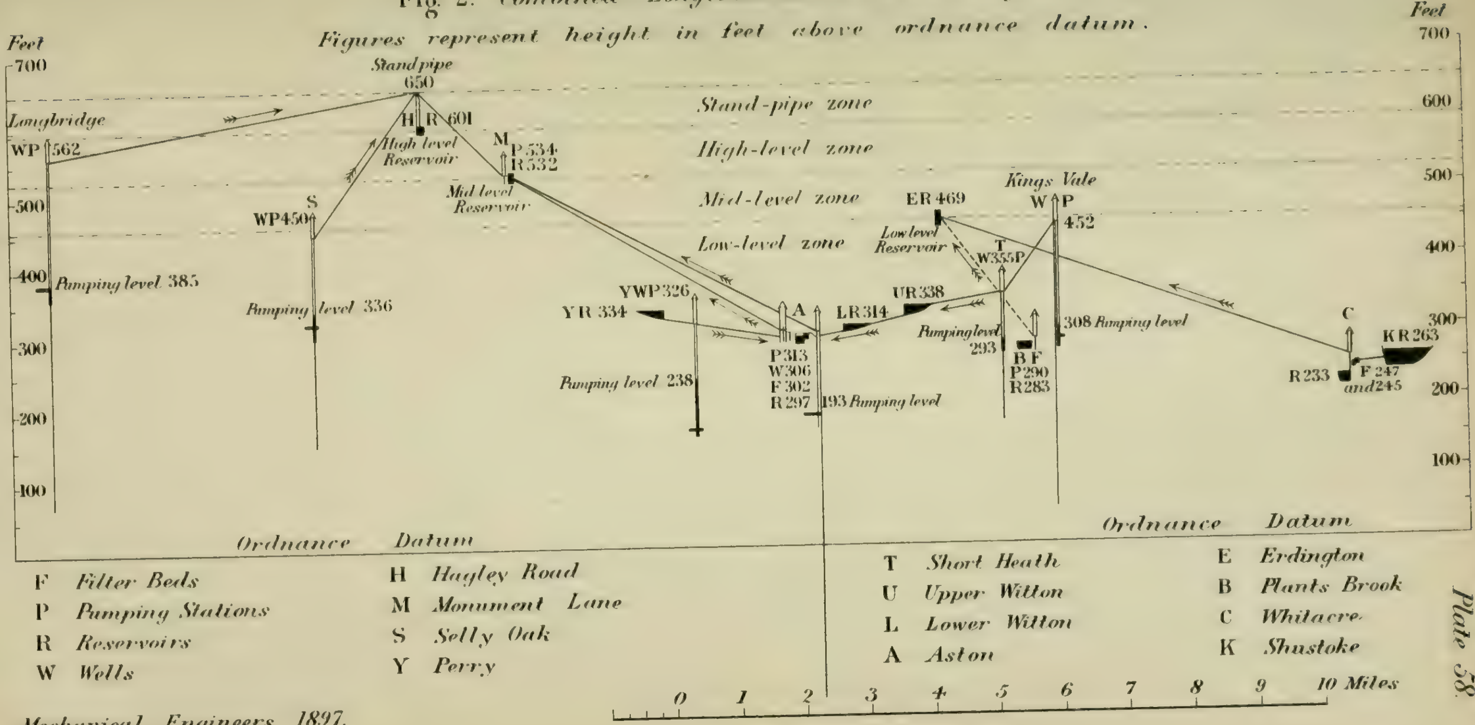
Mechanical Engineers 1897.

Plate 57.

BIRMINGHAM WATER WORKS.

Fig: 2. *Combined Longitudinal Sectional diagram.*

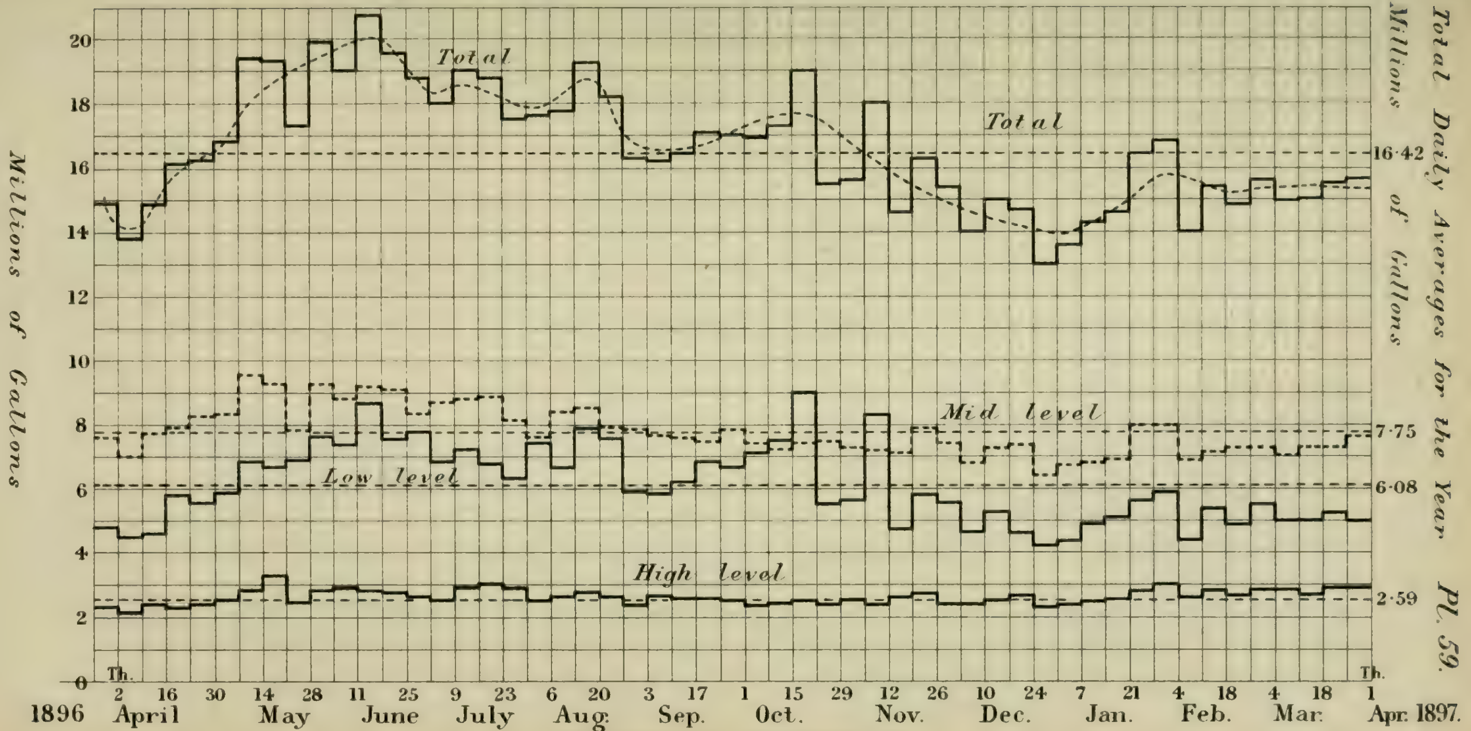
Figures represent height in feet above ordnance datum.



F	*Filter Beds*	H	*Hagley Road*	T	*Short Heath*	E	*Erdington*
P	*Pumping Stations*	M	*Monument Lane*	U	*Upper Witton*	B	*Plants Brook*
R	*Reservoirs*	S	*Selly Oak*	L	*Lower Witton*	C	*Whitacre*
W	*Wells*	Y	*Perry*	A	*Aston*	K	*Shustoke*

BIRMINGHAM WATER WORKS.

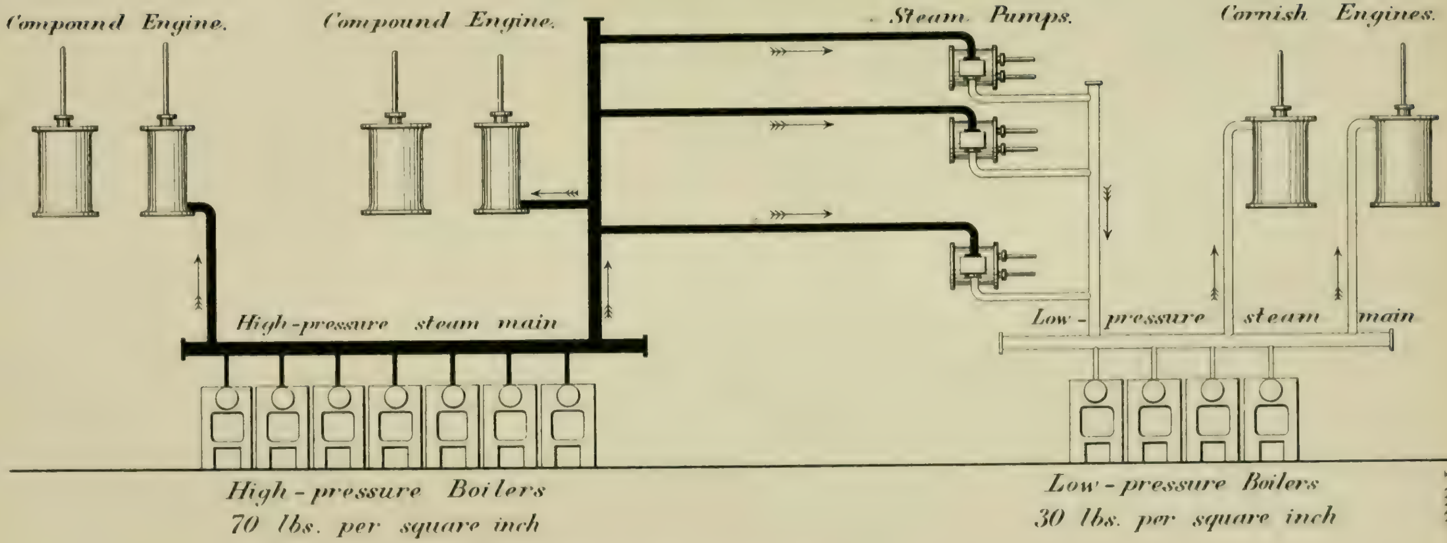
Fig. 3. *Water Consumption 1896 - 97.*



BIRMINGHAM WATER WORKS.

Whitacre Pumping Station.

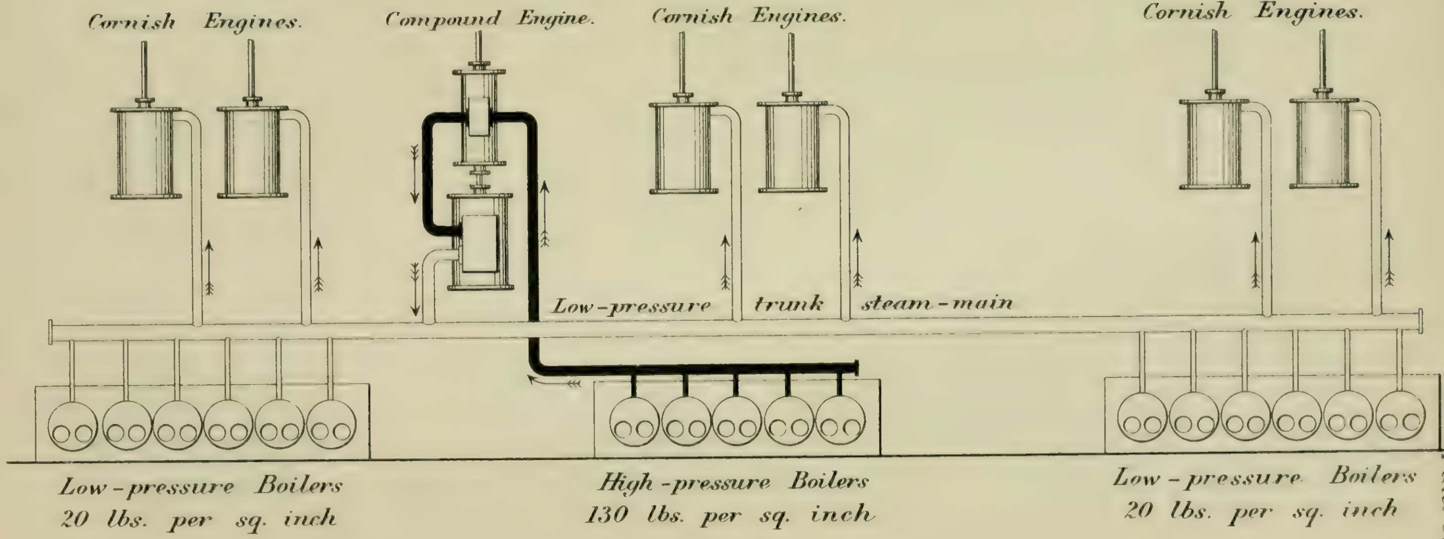
Fig: 4. *Steam Distribution.*



BIRMINGHAM WATER WORKS.

Aston Pumping Station.

Fig 5. *Steam Distribution.*



Mechanical Engineers 1897.

Aston Station.

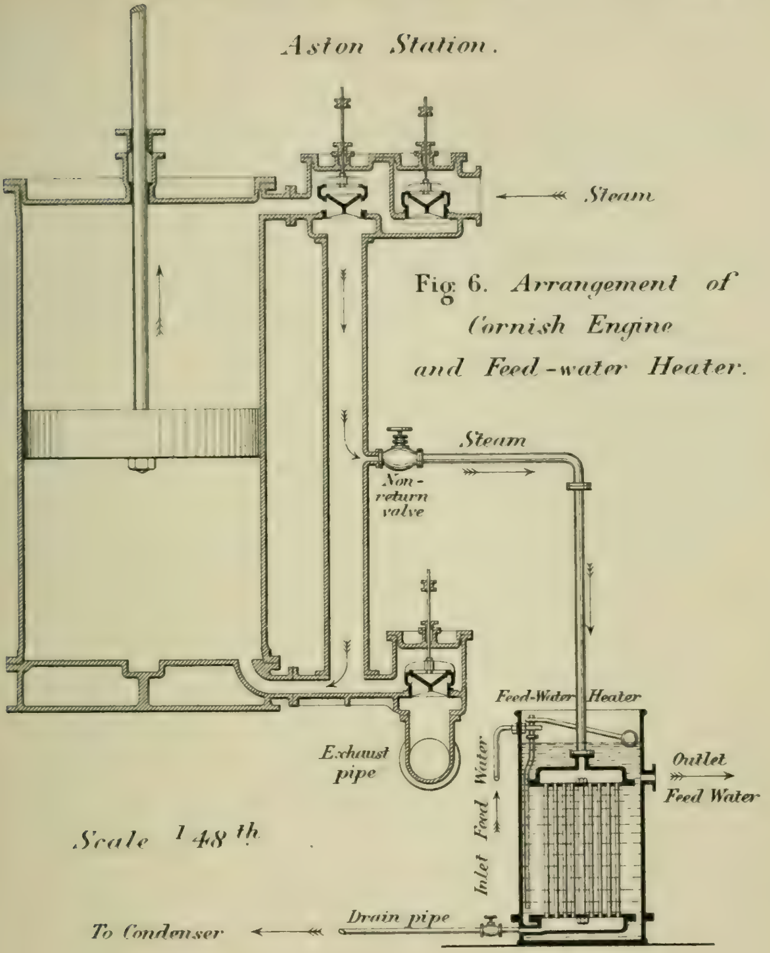
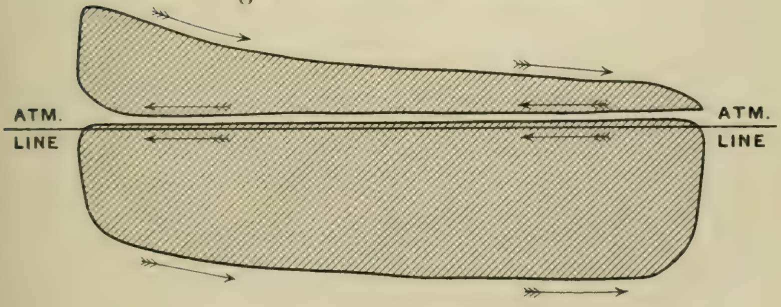


Fig. 6. *Arrangement of Cornish Engine and Feed-water Heater.*

Fig. 7. *Indicator Diagrams.*



QUICK-REVOLUTION ENGINES.

Steam Life-Boat Screw-Engine,

1865.

Scale 1/8th

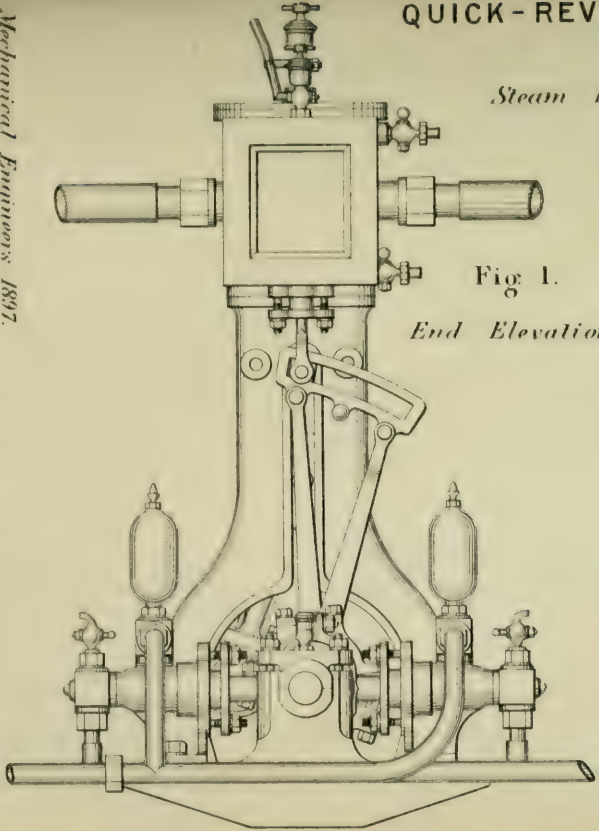


Fig. 1.

End Elevation.

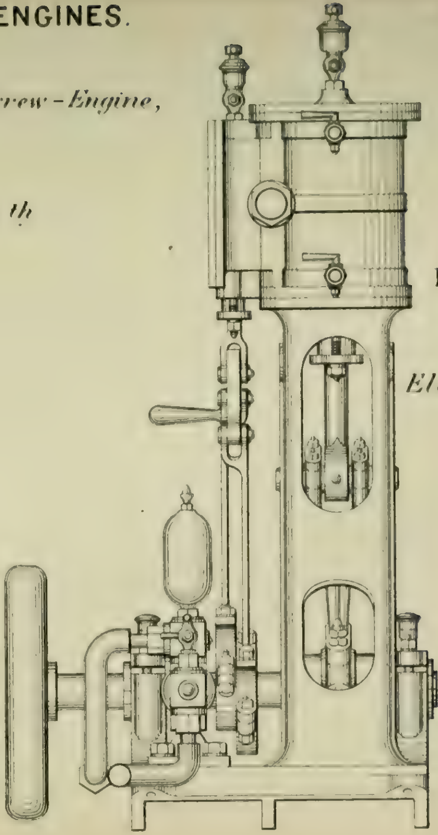


Fig. 2.

Side Elevation.

Mechanical Engineers 1897.

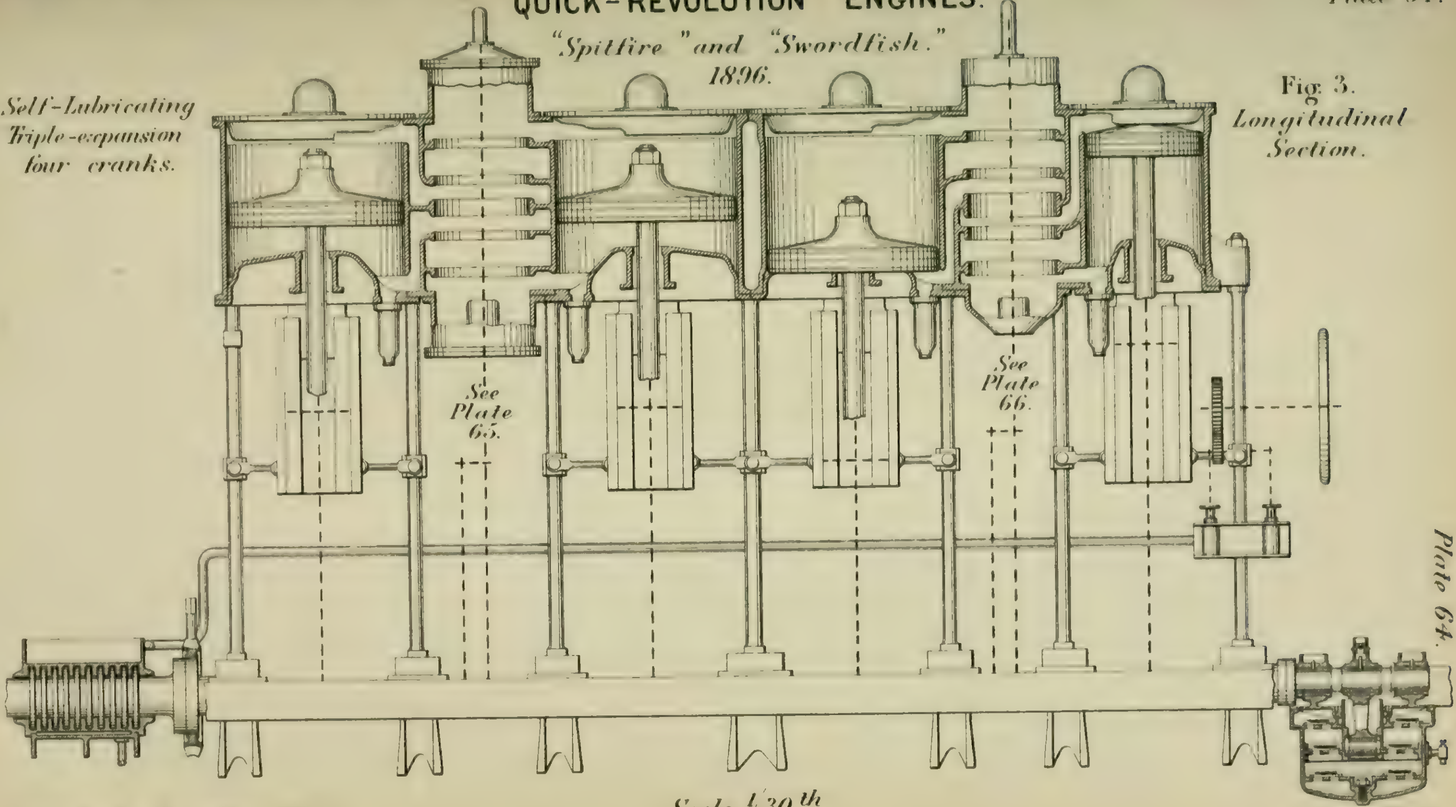
Scale 1/8th

QUICK-REVOLUTION ENGINES.

"Spitfire" and "Swordfish."
1896.

Self-Lubricating
Triple-expansion
four cranks.

Fig. 3.
Longitudinal
Section.



Scale 1/30th.

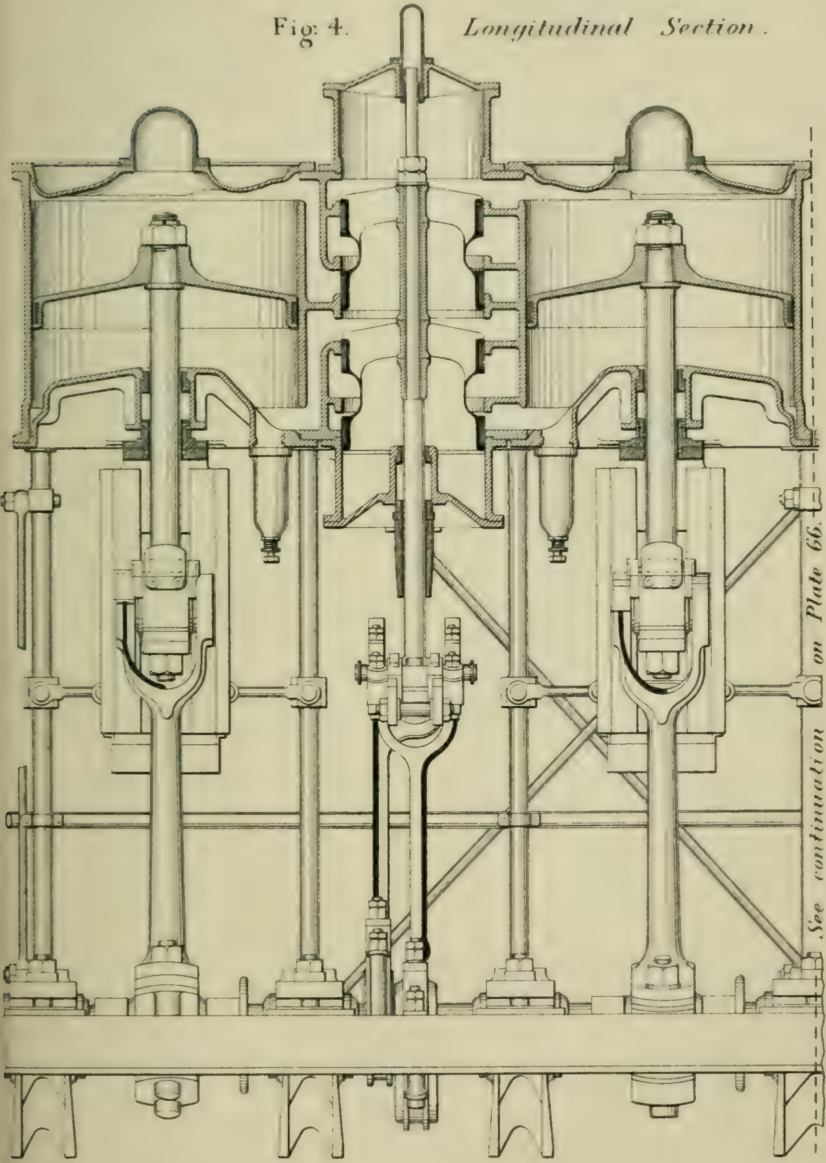
Mechanical Engineers 1897.

QUICK-REVOLUTION ENGINES.

"Spitfire" and "Swordfish" 1896.

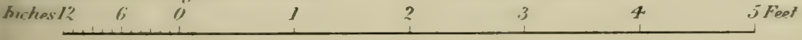
Self-Lubricating Triple-expansion four cranks.

Fig: 4. *Longitudinal Section.*



See continuation on Plate 66.

Mechanical Engineers 1897. *Scale 1/20th*

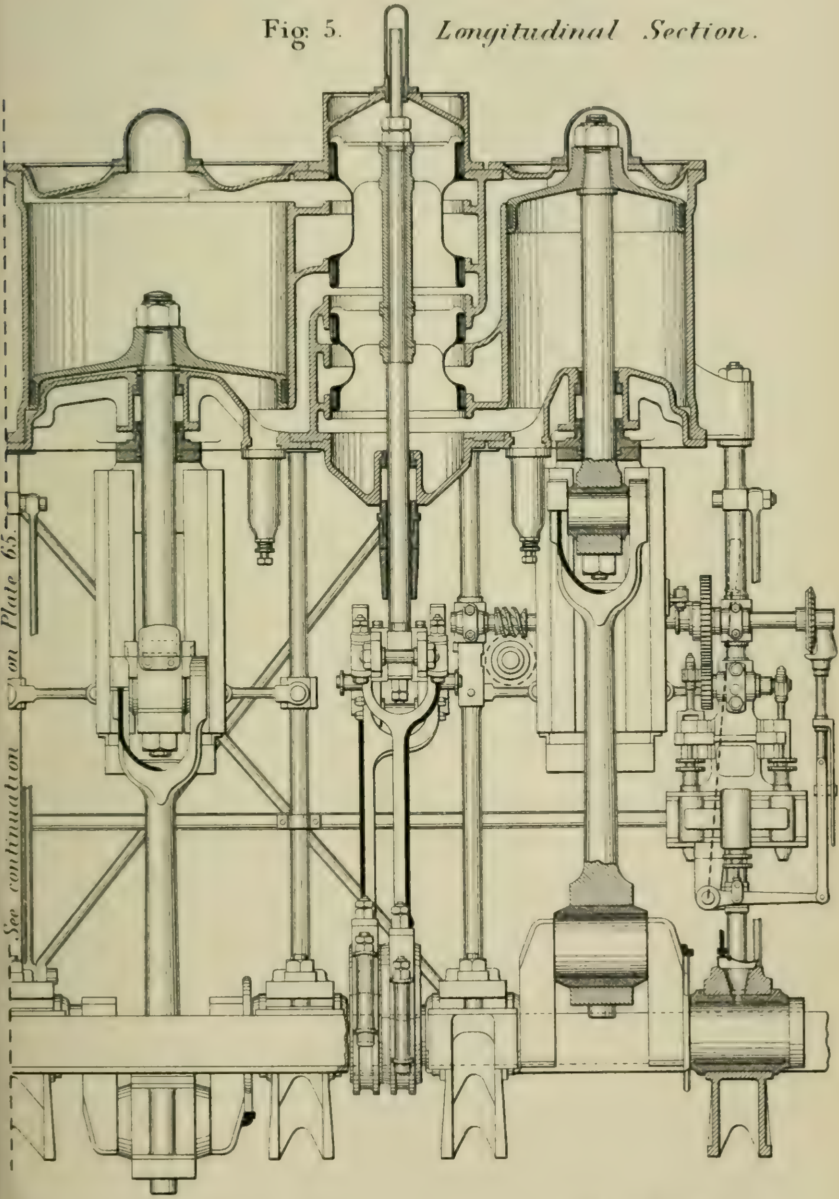


QUICK-REVOLUTION ENGINES. *Plate 66.*

"Spitfire" and "Swordfish" 1896.

Self-Lubricating Triple-expansion four cranks.

Fig. 5. *Longitudinal Section.*



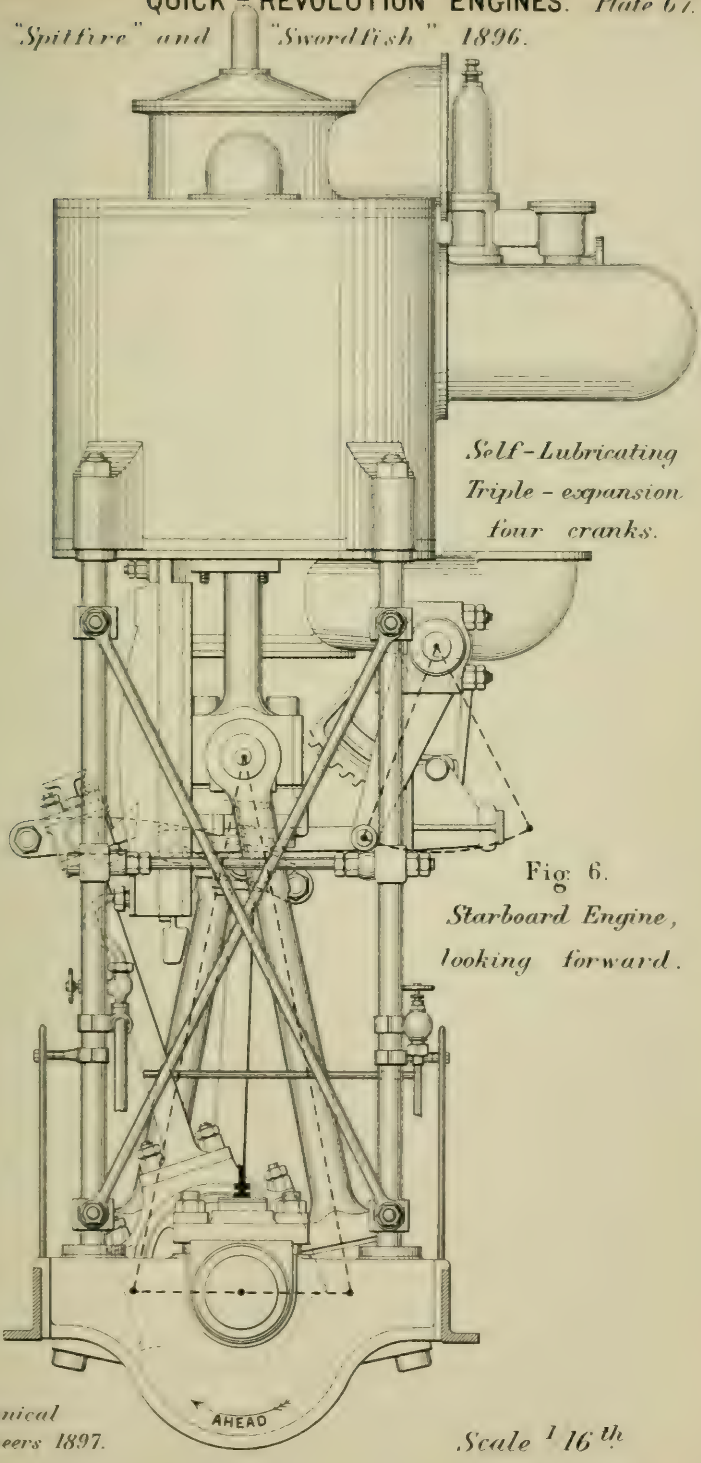
See continuation on Plate 65.

Scale 1/20th

Inches 12 6 0 1 2 3 4 5 Feet

QUICK - REVOLUTION ENGINES. *Plate 67.*

"Spitfire" and "Swordfish" 1896.



Self-Lubricating Triple-expansion four cranks.

Fig. 6.
Starboard Engine, looking forward.

Mechanical Engineers 1897.

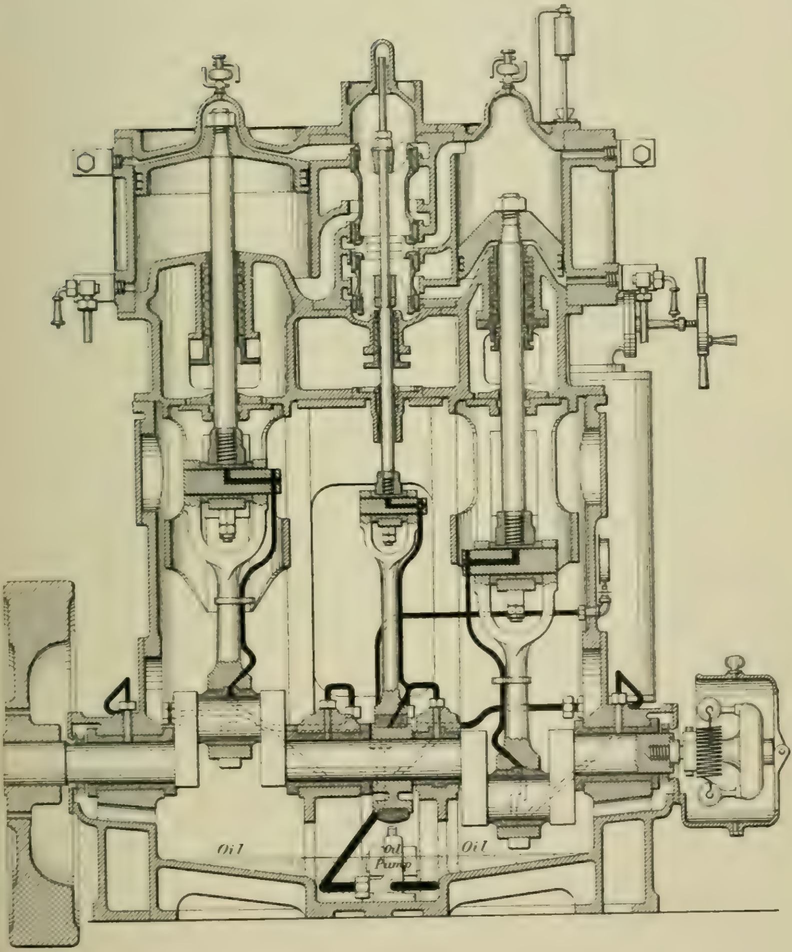
Scale 1/16th.

QUICK-REVOLUTION ENGINES. *Plate 68.*

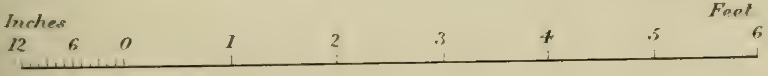
Self-lubricating Compound.

Two opposite Cranks.

Fig. 7. *Longitudinal Section.*



Mechanical Engineers 1897. *Scale 1/20th.*

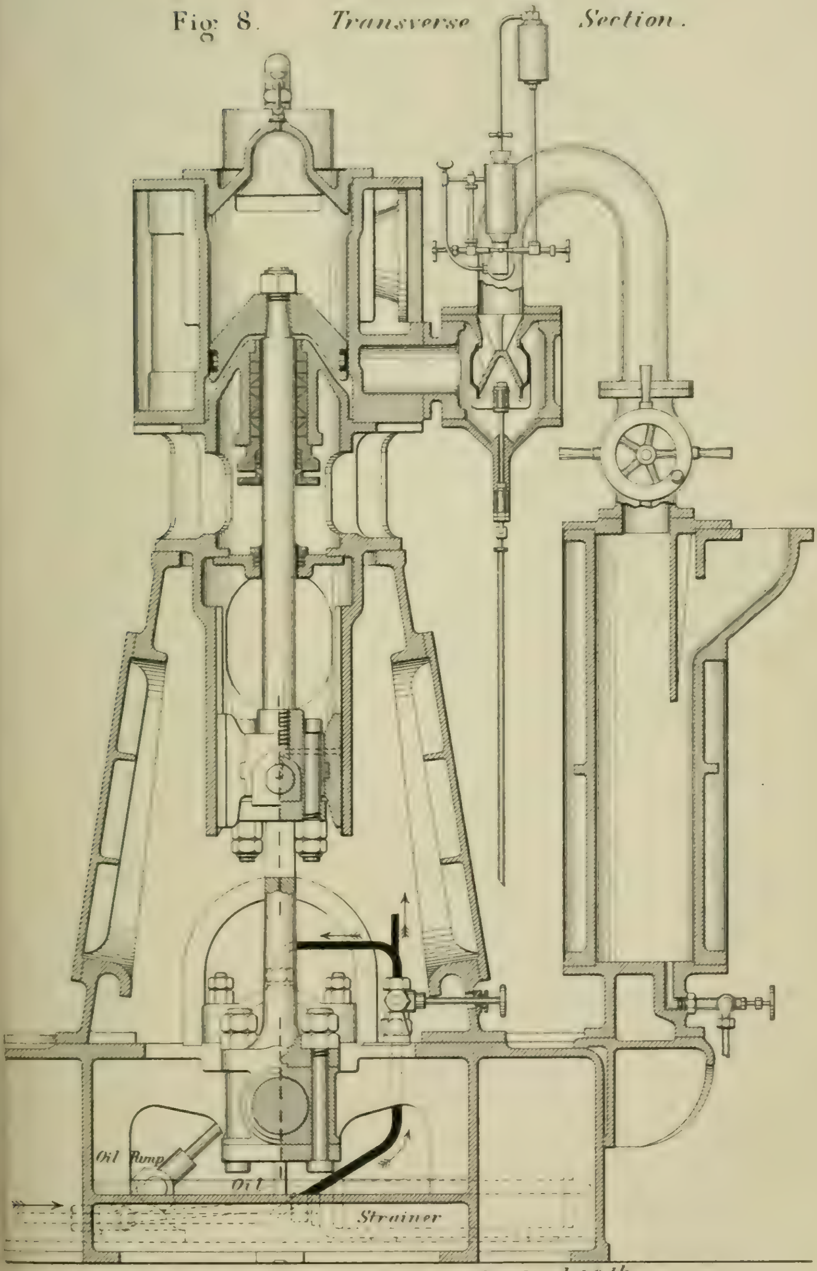


QUICK-REVOLUTION ENGINES. *Plate 69.*

Self-lubricating Compound.

Two opposite cranks.

Fig: 8. *Transverse Section.*



Mechanical Engineers 1897. *Scale 1/16th.*

Ins. 12 6 0 1 2 3 Feet 4

QUICK - REVOLUTION ENGINES.

Self-Lubricating Triple-expansion, Three equal cranks.

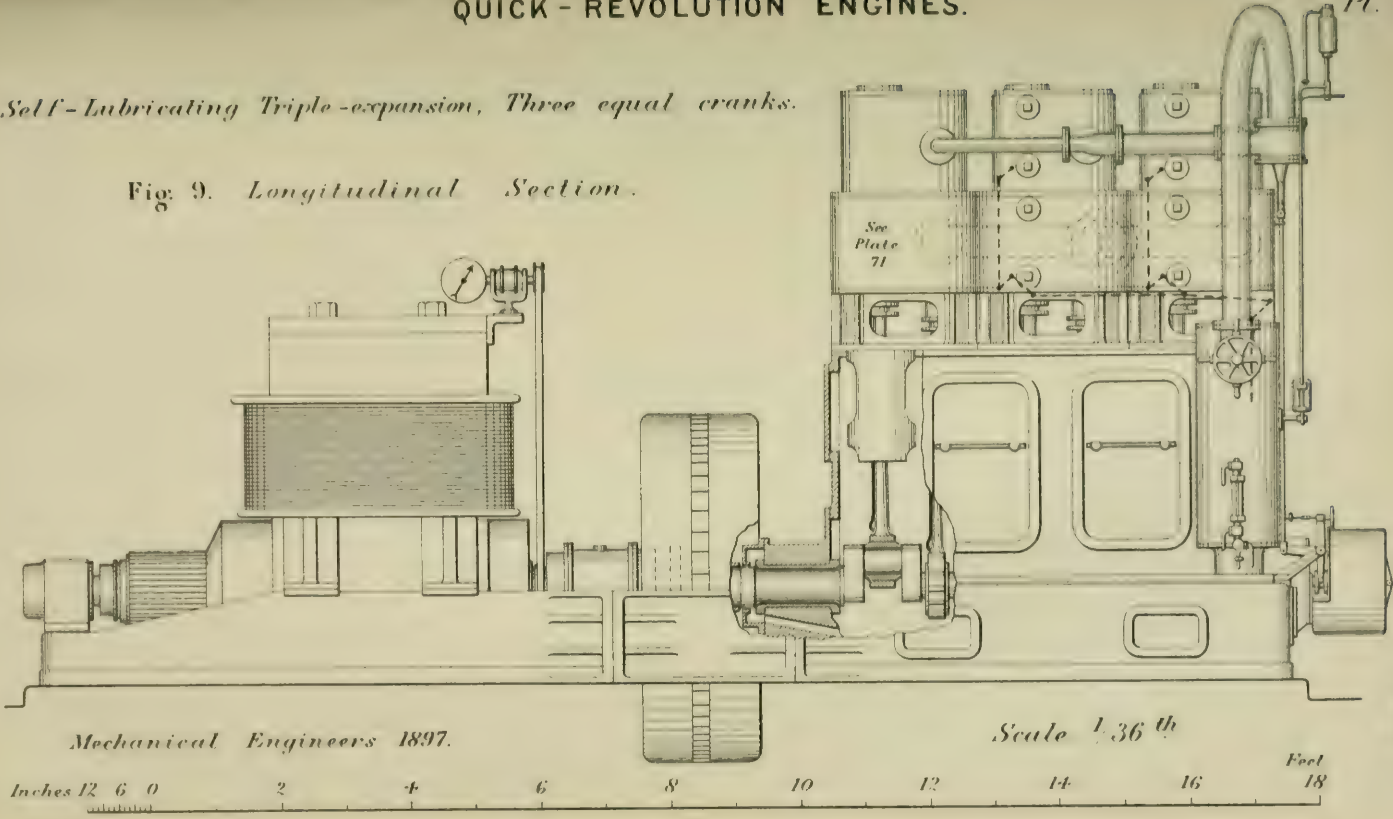


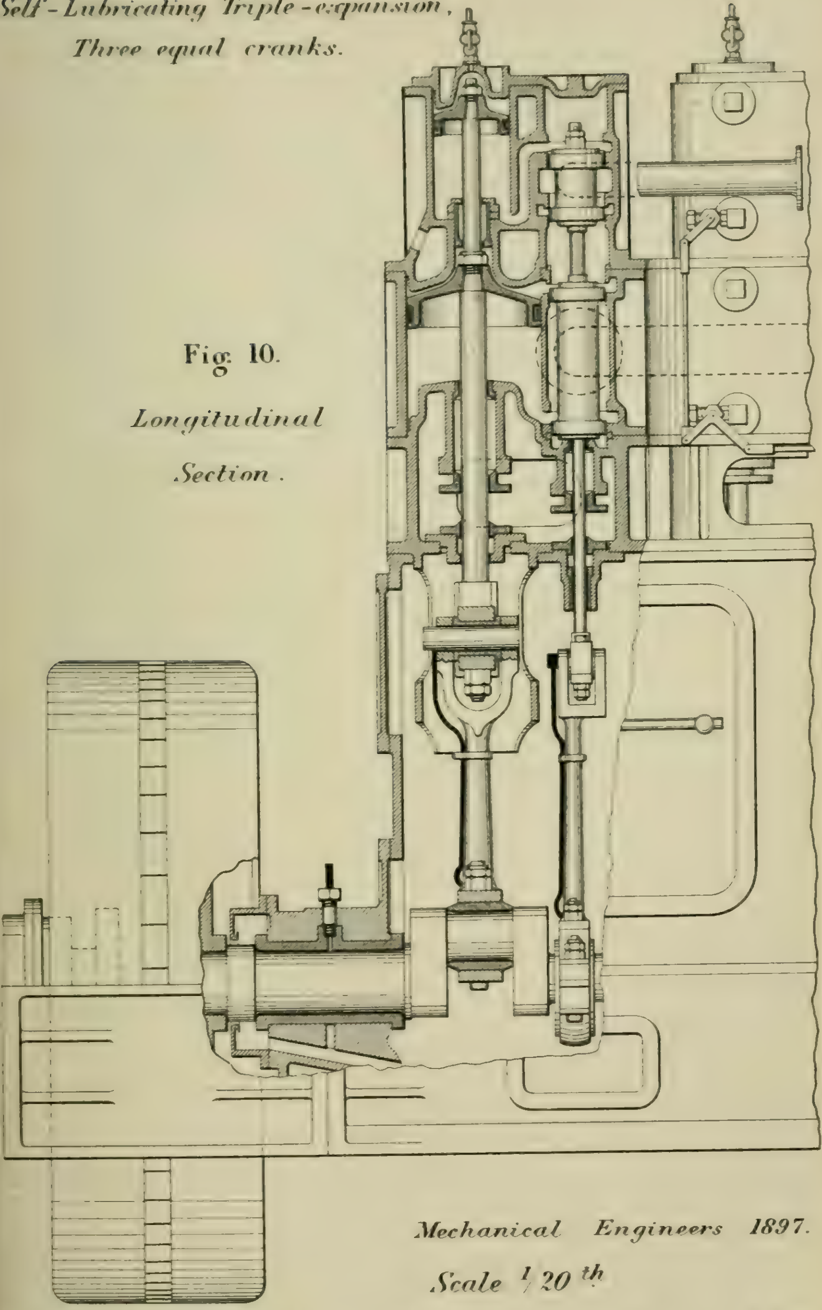
Fig: 9. *Longitudinal Section.*

Mechanical Engineers 1897.

Self-Lubricating Triple-expansion,
Three equal cranks.

Fig. 10.

Longitudinal
Section.



Mechanical Engineers 1897.

Scale 1/20th.

Ins. 12 6 0 1 2 3 4 5 Feet

Self-Lubricating Triple-expansion

Three equal cranks.

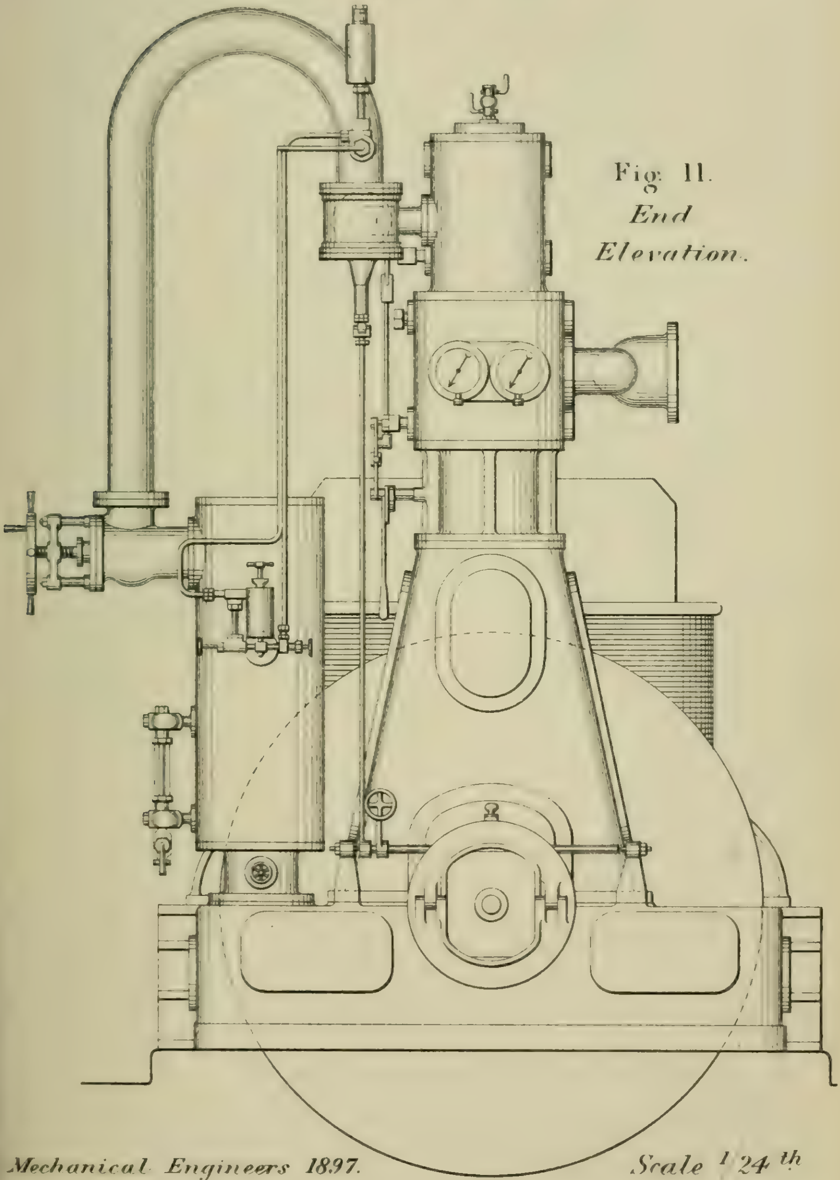


Fig. 11.
End Elevation.

Mechanical Engineers 1897.

Scale 1/24th

QUICK-REVOLUTION ENGINES.

Belliss 200 H P. Quick-Revolution Self-Lubricating Engines, Condensing.

Fig. 12. *Sunderland Electric-Supply Engine.*

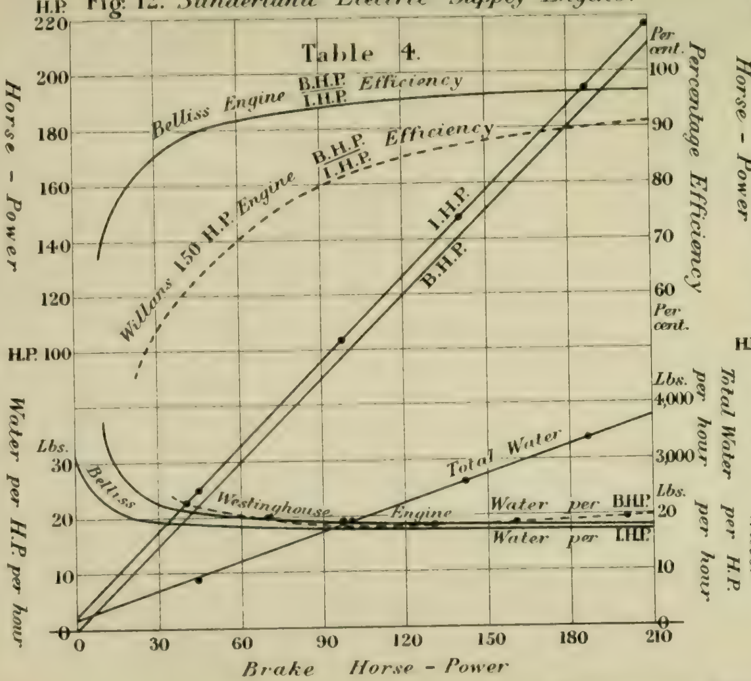
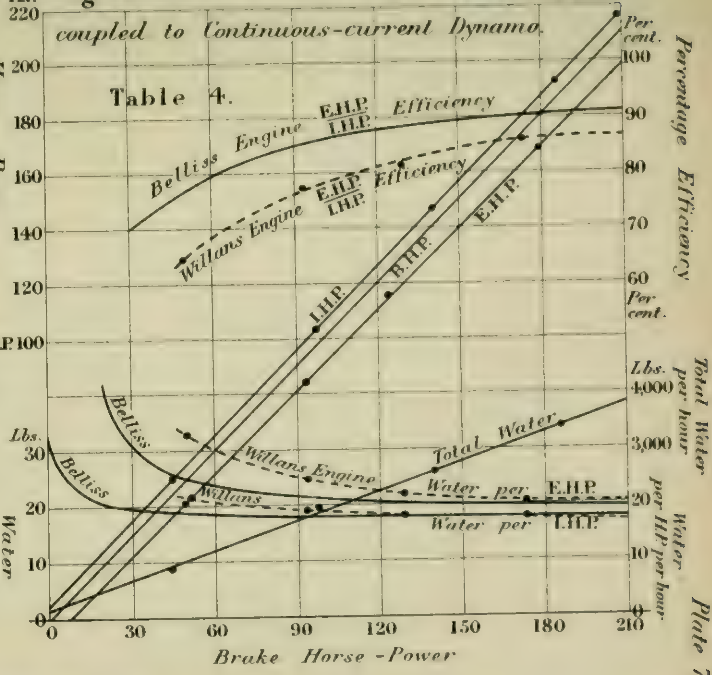


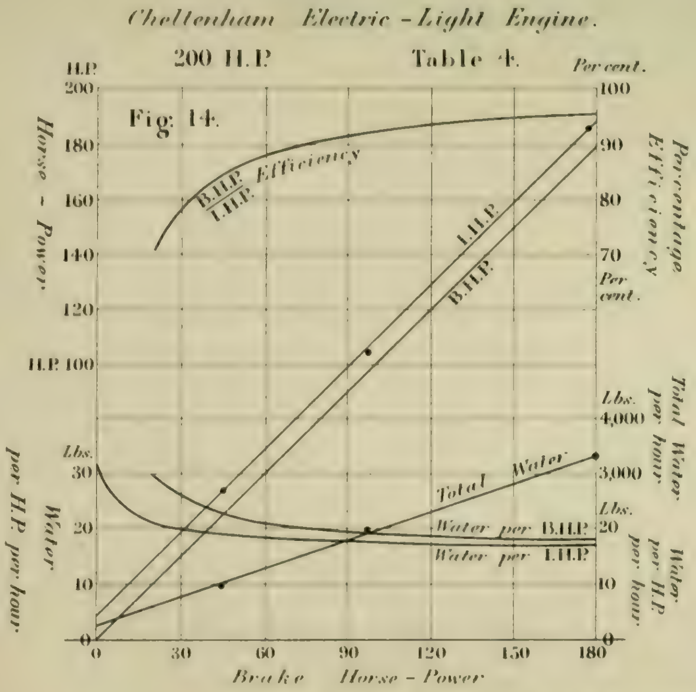
Fig. 13. *Sunderland Electric-Supply Engine, coupled to Continuous-current Dynamo.*



Mechanical Engineers 1897.

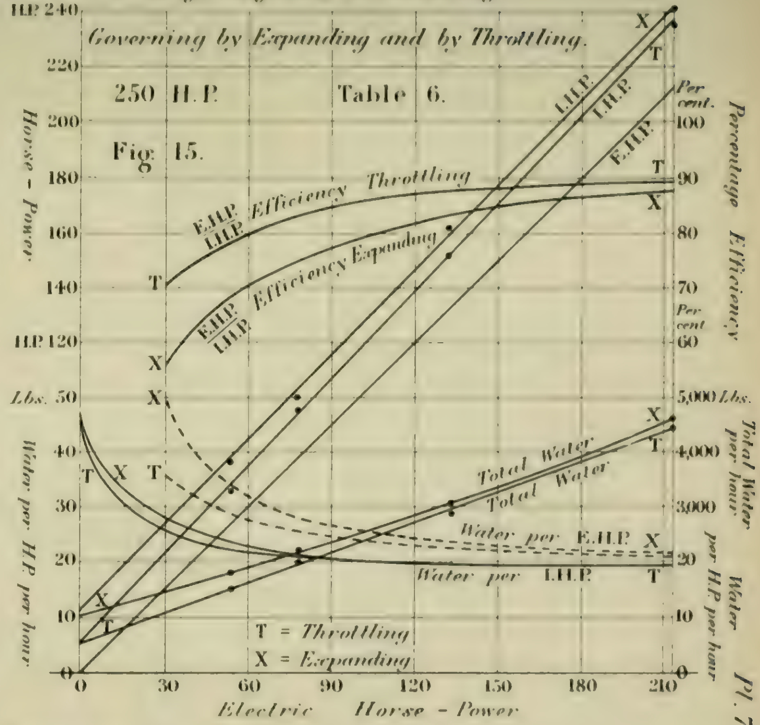
QUICK - REVOLUTION ENGINES.

Belliss Quick - Revolution Self - Lubricating Engines, Condensing.


Cheltenham Electric - Light Engine.

200 H.P. Table 4.

Fig: 14.

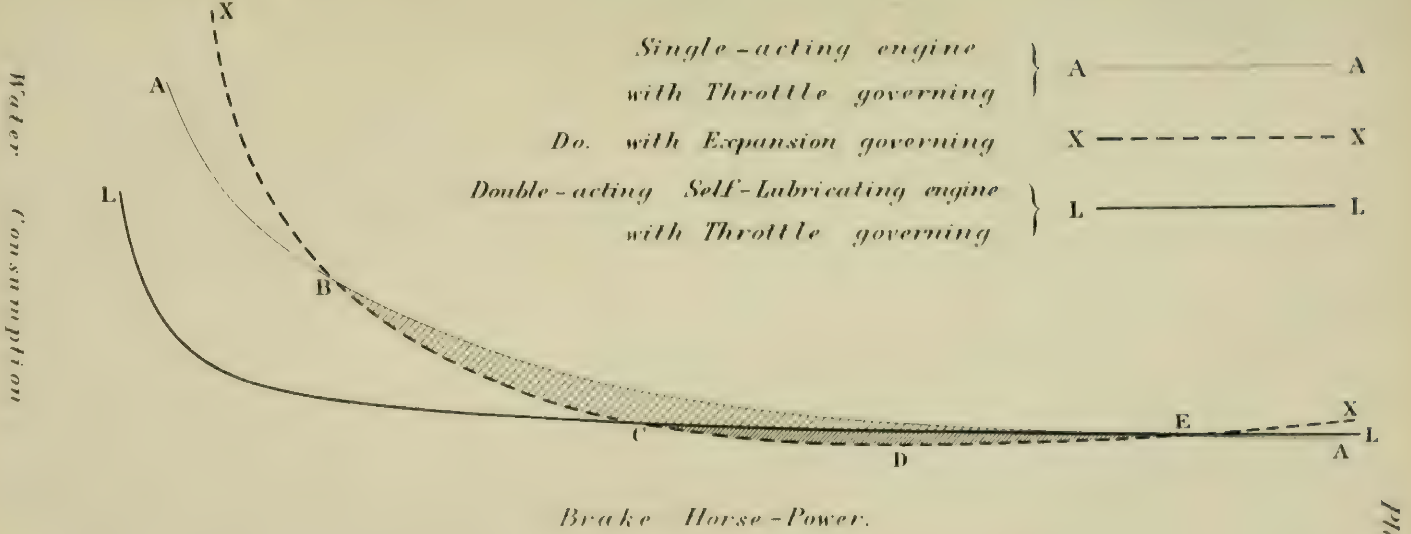

Governing by Expanding and by Throttling.

250 H.P. Table 6.

Fig: 15.

QUICK-REVOLUTION ENGINES.

Fig. 16. *Water Consumption per brake horse-power.*



QUICK-REVOLUTION ENGINES.

Mean-Effective-Pressure Gauge.

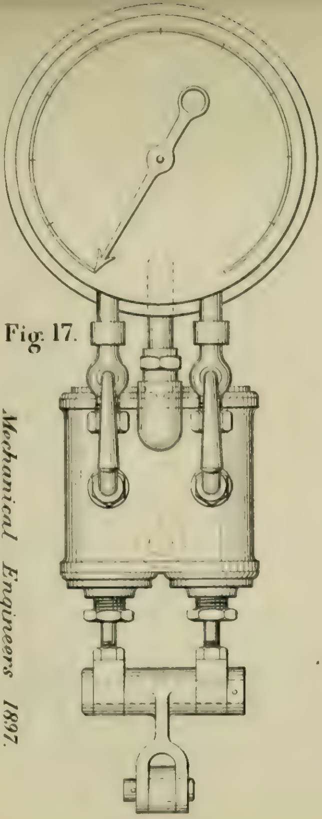


Fig. 17.

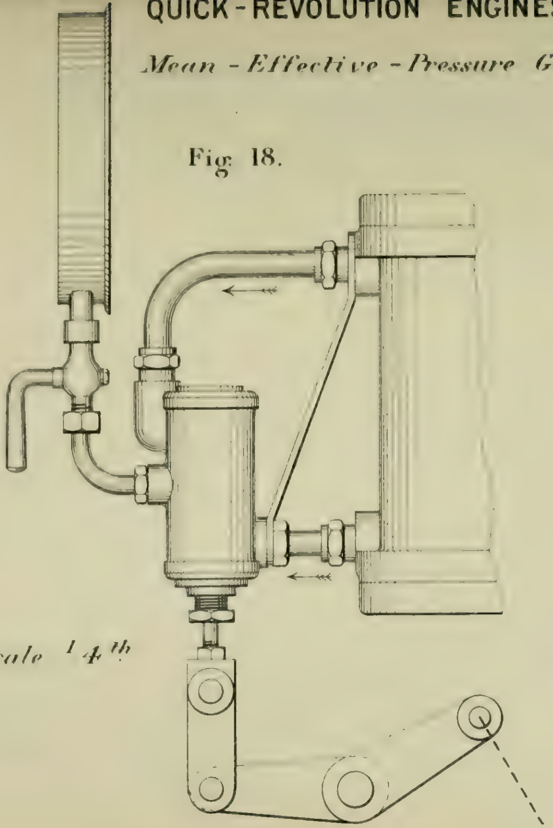


Fig. 18.

Scale 1/4th

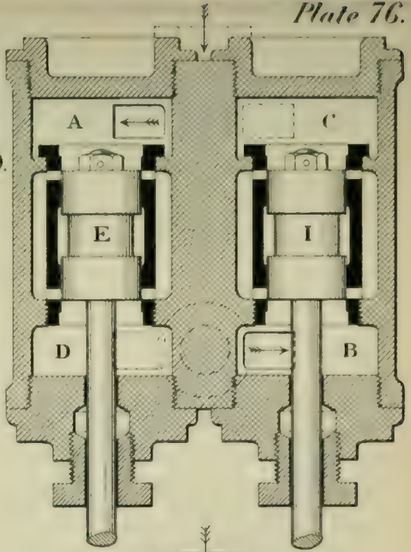


Fig. 19.

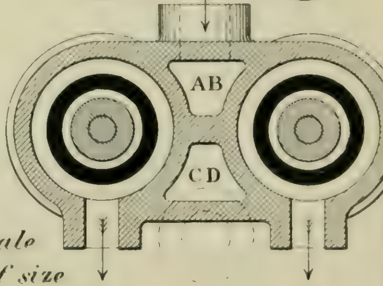


Fig. 20.

Scale half size

Plate 76.

QUICK-REVOLUTION ENGINES.

Model of Anti-Vibrator.

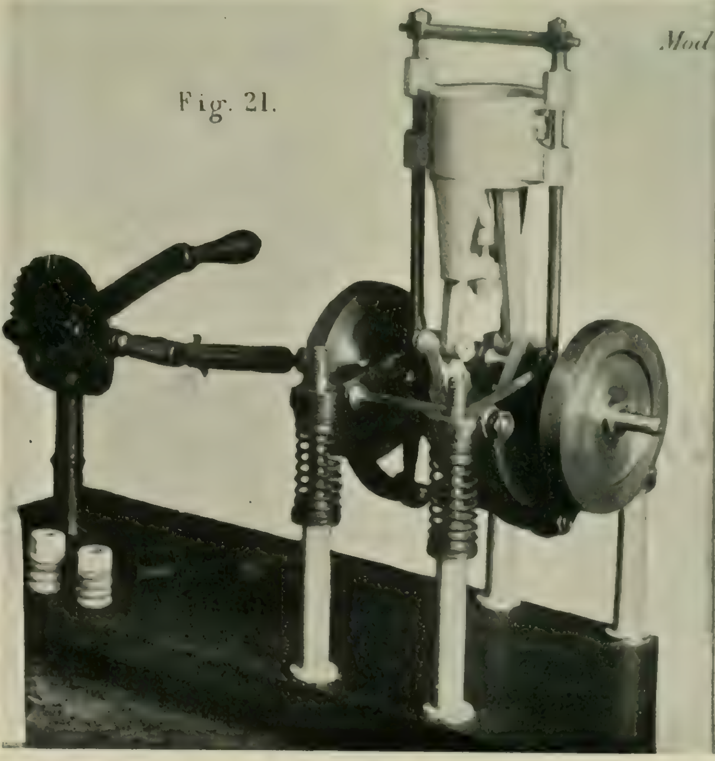


Fig. 21.

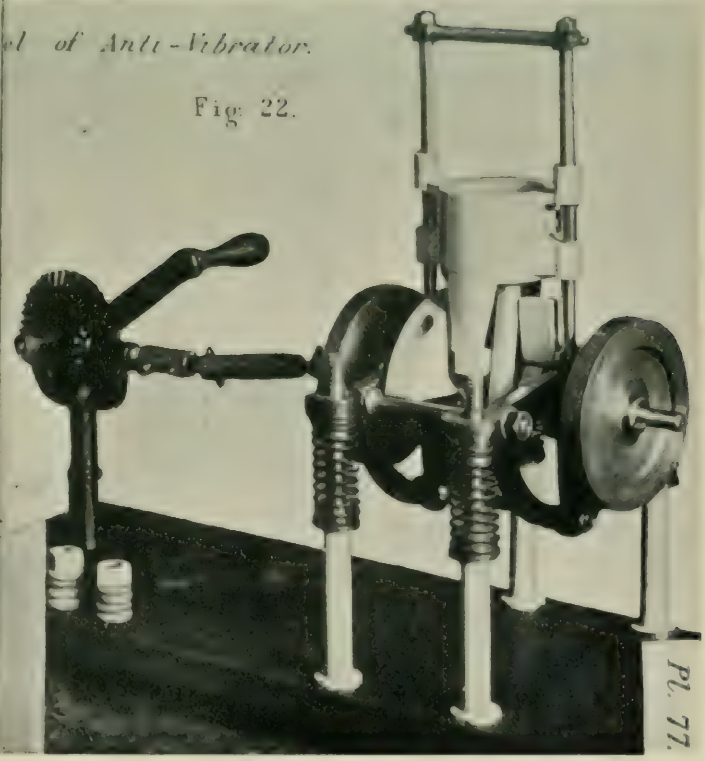


Fig. 22.

QUICK-REVOLUTION ENGINES.

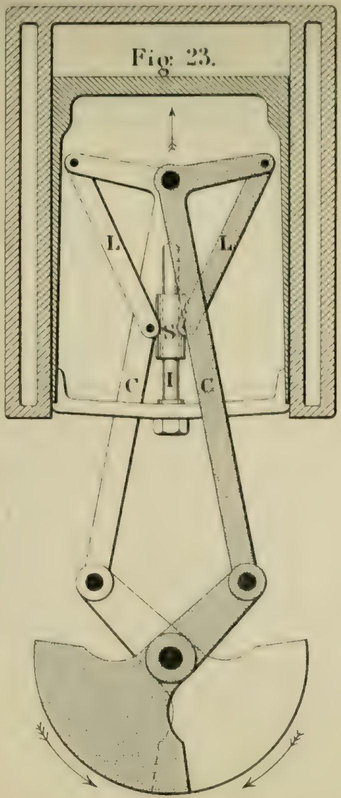


Fig: 23.

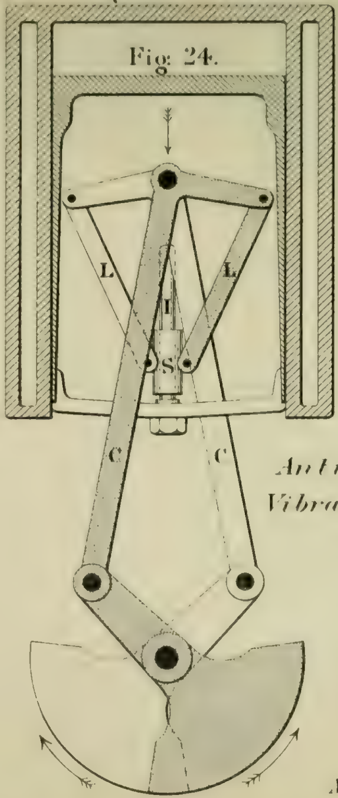


Fig: 24.

Anti -
Vibrator.

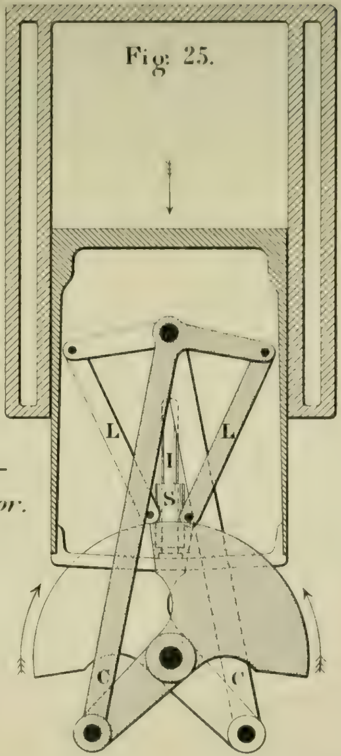


Fig: 25.

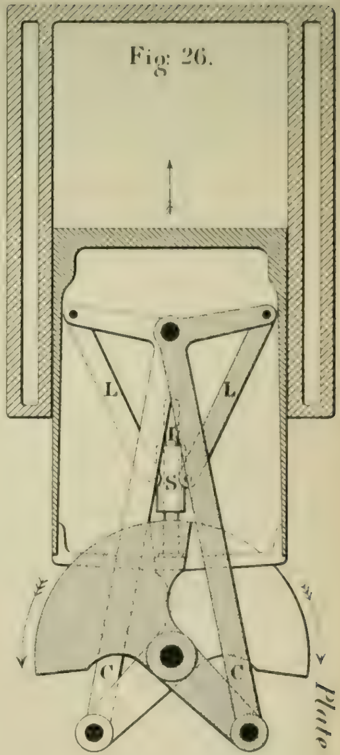


Fig: 26.

The Institution of Mechanical Engineers.

PROCEEDINGS.

November 1897.

The Autumn Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 3rd November 1897, at Half-past Seven o'clock p.m.; E. Windsor Richards, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President, referring to the testimonial voted by the members at the previous meeting, as recorded in the minutes just signed, exhibited the Silver Salver, which, agreeably with Mr. Forrest's wishes, had been selected for presentation to him, bearing the following inscription:—" Presented by The Institution of Mechanical Engineers to James Forrest in grateful acknowledgment of his unfailing courtesy and active kindness during nearly a quarter of a century 1873-1896 as Secretary of The Institution of Civil Engineers." This testimonial he should himself have the pleasure of presenting tomorrow on behalf of the Institution to Mr. Forrest, from whom the following letter had been received:—

Royal Victoria Hotel, St. Leonards-on-Sea, 2 November 1897.

The President, Council, and Members
of The Institution of Mechanical Engineers.

Gentlemen,

It was extremely gratifying to me to learn that when occupying the position of Secretary of The Institution of Civil Engineers the services then rendered to the Mechanical Engineers should have been deemed worthy of a testimonial. The handsome silver salver, bearing such a very complimentary inscription, now presented, is all the more flattering as coming from a sister Institution. I regret my inability to attend personally to receive this token of your regard. Therefore I must ask to be allowed to express in writing my very hearty thanks for it, and to assure you that the kind and friendly feeling which has prompted the gift will ever be remembered and appreciated.

With every respect, I remain, Gentlemen,
Yours faithfully,
James Forrest.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following sixty-nine candidates were found to be duly elected. One name which had been included in the ballot list had been withdrawn by the Council, and deferred for further enquiry.

MEMBERS.

Atsumi, Sadamoto,	Osaka, Japan.
Balkwill, Alfred John,	Wakefield.
Belliss, John,	Birmingham.
Berthiez, Charles,	Mulhouse.
Critchley, James Sidney,	Coventry.
Davies, Edmund Joseph,	Ipswich.
Elsworth, John Francis,	Alexandria.
Evers, Joseph Henry,	Leeds.
Harvey, Robert,	Glasgow.
Heaton, Charles,	Birmingham.
I'Anson, Joseph Coventry,	London.
Lupton, Hugh,	Leeds.
Mapplebeck, Edward,	Birmingham.
Marshall, Herbert,	Gainsborough.
Munro, Edward May,	Bristol.
Owens, Philip Robert,	Liverpool.
Pearce, Thomas,	Melbourne.
Price, Charles Edwin,	London.
Smallman, Herbert Spencer,	Wednesbury.

Spencer, John,	Keighley.
Spencer, Thomas Harris,	Wednesbury.
Swinburne, George,	Melbourne.
Warren, William,	Sunderland.
Watson, John B.,	Glasgow.
Widdowson, John Henry, Jun.,	Manchester.
Williams, Wyndham Henry,	Mozufferpore.
Wilson, William Campbell,	Thetford.
Wilson, William Henry,	Manchester.

ASSOCIATE MEMBERS.

Appleby, Harry Walton,	Bradford.
Atkinson, Robert Ernest,	Leicester.
Baker, John,	Birmingham.
Ball, John,	Cairo.
Beckton, William Rushworth,	London.
Bedbrook, James Albert Harvey,	Newcastle-on-Tyne.
Blakiston, Ralph,	Liverpool.
Craig, Alexander,	Coventry.
Frerichs, Jacob Andrew,	Boksburg.
Ganu, Gaugadhar Vishnu,	Bolton.
Griffiths, Alfred,	Manchester.
Irvine, Archibald John,	Johannesburg.
Johns, Cosmo,	Briton Ferry.
Ketley, Charles Bosworth,	Birmingham.
Moule, Frederick Oswald,	Lincoln.
Player, Ralph,	Tipton.
Porter, Stanley William,	Hull.
Rogers, William Ivy,	Birmingham.
Rolf, George,	Newcastle-on-Tyne.
Ruthen, Charles Tamlin,	Swansea.
Scott, Newton L.,	London.
Sharpley, George Ruston,	Lincoln.
Spencer, Henry Wilmot,	London.
Stockwell, Charles Edward,	Sydney.
Talbot, William John,	Birmingham.
Thompson, Herbert,	Sheffield.

Turner, George Robert,	Newcastle-on-Tyne.
Ward, John Cecil,	London.
Whale, Ralph Abrahams,	Sheffield.

ASSOCIATES.

Prior, James D.,	Birmingham.
Smith, William Henry,	London.

GRADUATES.

Allan, George, Jun.,	Birmingham.
Atherton, Percy William,	London.
Baxandall, Richard Fitzgerald,	Bradford.
Bullock, Richard Cecil,	Bath.
Evetts, William, Jun.,	Horwich.
Locket, Athol,	London.
Nixon, Charles Basil,	Horwich.
Pillatt, Andrew Ernest,	Nottingham.
Pullar, Frederick Pattison,	Bridge of Allan.
Rootham, Howard Melville,	London.

The President announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows :—

PRESIDENT.

E. Windsor Richards,	Low Moor.

VICE-PRESIDENTS.

Samuel W. Johnson,	Derby.
Francis C. Marshall,	Newcastle-on-Tyne.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
William Dean,	Swindon.
Bryan Donkin,	London.
Arthur Keen,	Birmingham.
Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

Of these the following offered themselves for re-election:—

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
William Dean,	Swindon.
Bryan Donkin,	London.

The following nominations had also been made by the Council for the election at the Annual General Meeting:—

PRESIDENT.

Samuel W. Johnson,	Derby.

VICE-PRESIDENTS.

Election as Member.		
1869.	Arthur Keen,	Birmingham.
1888.	Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

MEMBERS OF COUNCIL.

1875.	Edward B. Ellington,	London.
1879.	H. Graham Harris,	London.
1860.	Henry Lea,	Birmingham.
1897.	Alfred Morcom,	Birmingham.
1874.	T. Hurry Riches,	Cardiff.

The President reminded the Meeting that, according to the Rules of the Institution, any Member or Associate Member was now entitled to add to the list of candidates.

The following nomination was made by Mr. James P. Maginnis, Member:—

VICE-PRESIDENT.

1872.	Sir Benjamin A. Dobson,	Bolton.

The following nomination was made by Mr. Samuel George Lovell, Associate Member:—

MEMBER OF COUNCIL.

1890.	William George Walker,	London.

The President announced that the foregoing names, subject to the consent of the two added, would accordingly constitute the nomination list for the election of officers at the Annual General Meeting.

The PRESIDENT said that, in conformity with the notice given in the circular announcing the present meeting, the appointment of a successor to the Secretaryship had now to be made by the Members and Associate Members. One hundred applications having been received for the appointment, it would readily be imagined how difficult a matter it had been for the Secretarial Committee of the Council to select one from so many gentlemen competent to fulfil the position of Secretary to their satisfaction. The Committee had had to consider many qualifications, including general education, knowledge of languages, technical experience, literary attainments, and secretarial abilities. It had taken some considerable time to bring the number down to nine, with whom the Committee had then had interviews severally, in order carefully to select from them the one whom they considered most likely to serve the best interests of the Institution. Looking at the matter from an impartial point of view, he could conscientiously say that throughout his experience as President he had never known a subject taken up by the Council which had received more careful attention; they had borne in mind constantly the one object of selecting the best man. After a considerable time and several meetings, they had been able to reduce the number to two; and then the final choice became a task of extreme difficulty. At last, after again going carefully through all the points he had named, they had come to the unanimous conclusion that the best man they could recommend for appointment by the members as successor to the Secretaryship of the Institution was Mr. Edgar Worthington, who was at present employed as a managing engineer in the works of Messrs. Beyer, Peacock and Co., Gorton Foundry, Manchester. He therefore moved the following resolution:—"That Mr. Edgar Worthington be appointed Secretary of the Institution." It was contemplated that the duties of the new Secretary should commence in January next; and he would be helped by Mr. Bache up to the end of the Annual General Meeting in February. It was hoped by that time the publication of the Proceedings, which was much in arrear, would be brought up more nearly to date. He had no doubt in his own mind, and the Council were unanimous in anticipating, that

Mr. Worthington would be a worthy successor to the Secretaryship, and would promote to the utmost of his ability the welfare of the Institution.

Mr. Samuel W. Johnson, Vice-President, had great pleasure in endorsing everything the President had said with regard to Mr. Worthington. The Secretarial Committee of the Council had taken a great deal of pains over the matter, and were satisfied that they had selected the best man for the position. He had great pleasure in seconding the motion.

The Resolution was unanimously agreed to.

The President announced that the Council had decided to mark their appreciation of the obliging services rendered for the recent Jubilee Meeting of the Institution in Birmingham, by presenting a Silver Salver bearing a suitable inscription to the two Honorary Local Secretaries, Mr. W. Bayley Marshall and Mr. Eric M. Carter.

After the reading of a Supplementary Paper by the same author, the adjourned Discussion was resumed and concluded upon the following Paper, which had been read and partly discussed at the Spring Meeting:—

"Experiments upon Propeller Ventilating Fans, and upon the Electric Motor driving them;" by Mr. William George Walker, of London.

At Half-past Nine o'clock the Meeting was adjourned to the following evening. The attendance was 121 Members and 85 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Thursday, 4th November 1897, at Half-past Seven o'clock p.m.; E. Windsor Richards, Esq., President, in the chair.

The following Papers were read and discussed :—

"Diagram Accounts for Engineering Work;" by Mr. John Jameson, of Newcastle-on-Tyne.

"Mechanical features of Electric Traction;" by Mr. Philip Dawson, of London.

The Discussion which had been commenced upon the latter Paper was adjourned, to be continued at the following Meeting.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in allowing the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at a Quarter to Ten o'clock. The attendance was 89 Members and 81 Visitors.

(*Read* 30 *April* 1897.)

EXPERIMENTS UPON PROPELLER VENTILATING FANS, AND UPON THE ELECTRIC MOTOR DRIVING THEM.

By Mr. WILLIAM GEORGE WALKER, of London.

Former Experiments.—In 1892 the author read a paper to this Institution (Proceedings, page 514) upon experiments on the arrangement of the surface of a screw-propeller; and in the discussion he mentioned (page 561) some experiments which he had made with Air Propellers, in order to try the effect of the thickness of the blades. In 1893 at the Nottingham meeting of the British Association he read a note on some experiments which he had made with Ventilating Fans having blades of various cross sections. Those preliminary trials led him to undertake the further experiments described in the present paper, which have been carried out during 1895–6 in his laboratory in Westminster. The primary purpose was to ascertain :—

1. Whether this kind of fan follows the ordinary laws respecting the mutual relations of speed of fan, power absorbed, and amount of air discharged.

2. The general characteristics regarding the speed of fan, power absorbed, and quantity of air discharged, with different angles of the blades.

3. The effect of fans differing from one another only in the cross section of their blades.

As he was not acquainted with any systematic experiments upon this kind of fan, the investigation of the relations of speed, power absorbed, and air discharged was a necessary preliminary to the modification arising from different angles and shapes and cross sections of the blades. The knowledge already acquired on the subject is confined principally to the centrifugal form of ventilator, and may be said to consist of a tolerably accurate and complete determination of those characteristics of performance which are common to all centrifugal fans of ordinary pattern, together with a somewhat vague appreciation of the character of the difference in design upon which the efficiency of a centrifugal fan depends.

Propeller Ventilating Fans.—The experiments on the Propeller Ventilating Fans showed that, in fans tried under the same conditions, the relations of speed of fan, power absorbed, and air discharged, are in accordance with the ordinary laws. The propeller, or helical form of fan as it is sometimes called, is essentially a ventilator, its principal object being to move large volumes of air at atmospheric pressure. It is unable to maintain a static pressure of air, which would be absolutely necessary if the air were met by opposing resistances. The propeller ventilating fan is of use where comparatively large quantities of air have to be exhausted from a building; its volumetric efficiency is therefore of much greater importance than its pressure efficiency, and in many cases is also of greater importance than its mechanical efficiency. All the results given in the present paper are with fans having a free discharge, the outlet being practically equal in area to the inlet of the fan. The ordinary centrifugal blowing fan generally works with a contracted outlet, its static pressure is comparatively high, and its mechanical efficiency is a maximum at a certain contraction of the outlet which gives a certain static pressure, while its volumetric efficiency is correspondingly low. The converse is the case with the propeller ventilating fan; its volumetric efficiency is a maximum with free discharge, and rapidly falls off with any baffling of the outlet pipe. It is important to avoid giving any shock to the air; the outlet and inlet should be as free as possible; sharp turns or blocking in the delivery pipe may reduce the efficiency to a considerable extent, owing to the fact that the flow of air is not assisted by any static pressure, but is due only to its velocity.

Experimental Apparatus.—Seventeen three-bladed fans were tried, all 23¾ inches diameter, specially constructed for these experiments; they are shown in Figs. 1 to 17, Plate 79. The fans were driven by an electric motor, fixed centrally to a cast-iron frame in the rear of the fans, Figs. 18 and 19, Plate 80, which were keyed to the spindle of the armature, and were thus driven direct at the same speed as the motor. The latter was a continuous-current series-wound machine of about one-third of an electrical horse-power. The current was taken off the 100-volt mains of the Westminster Electric Supply Corporation. The air was delivered through a tube 24 inches bore and 4 feet long, Figs. 21 and 22, Plate 81, made of stiff sheet-iron and placed concentric with the fan axis and at the end of the frame. The speed of the fan was indicated by a tachometer, which was attached by Dr. Hook's joint to the spindle of the motor, and was read to two revolutions per minute. The usual meters were employed for registering the number of volts and ampères. The speed of the motor was varied by means of electrical resistances. In most of the experiments the fans were run at a speed of 600 revolutions per minute; the speed was kept constant during each experiment by the adjustment of a suitable form of resistance. The volts in the supply mains were found to vary somewhat, which had an effect on the speed of the motor; during certain times of the day an almost continuous process of adjustment of the electrical resistance was necessary, in order to keep the volts quite constant.

The velocity of the air was measured by an anemometer of $2\frac{3}{4}$ inches diameter, placed at the outer end of the delivery tube, as shown in Figs. 21 and 22, Plate 81. The velocity varied greatly in different positions in the same cross section of the tube; a smooth brass rod 5–16ths inch diameter was placed horizontally across the end of the tube, to which the anemometer was attached, so that it could be tried at different positions on the rod. The centre of the anemometer moved in the horizontal diameter of the tube for all positions on the rod, and the instrument always moved in the same plane across the current.

The brake horse-power of the motor was obtained by a dynamometric brake, of which the arrangement is shown in Fig. 20, Plate 80. The fan having been removed, the brake pulley was fixed in the same position upon the spindle. The brake was highly effective; it was sensitive, yet ran steady with no oscillation. The pulley was of cast-iron, 9·4 inches diameter, with smooth circumference; it ran true, and a fine silk cord was wound once round it, the lower end being attached to the scale pan, and the upper end to a Salter's balance hung above the pulley and perpendicularly over the scale pan. The difference between the pull on the balance and the weight in the scale pan, multiplied by the circumference of the pulley and the number of revolutions per minute, and divided by 33,000, gave the brake horse-power. The pull and the weights in the scale pan were read in ounces. The silk cord was in direct contact with the surface of the pulley, and no cleats were employed to keep it on.

Measurement of Air Discharge.—It is difficult to conduct experiments with fans so as to obtain reliable results, especially in a long series of experiments extending over considerable time, when slight variations in the conditions may affect the results to a material degree. Changes due to slight variations in the position or condition of the apparatus, atmospheric changes of temperature and pressure and moisture, or alteration in condition of the room in which the experiments are made, all tend to affect the results. Having chosen the anemometer method for measuring the delivery of the air, the author made some experiments with a thin plate of small area, attached to the end of a thin well-balanced lever, and placed in the delivery tube so that the air impinged normally against its surface; it was adjusted at right angles to the stream of air by twisting by hand a wire, which formed the fulcrum of the lever, through an angle proportional to the pressure on the plate; the pressure being thus known, the velocity of the air can be calculated from it. This is somewhat similar to the Pitot tube method, which also measures the dynamic pressure of the air. With high velocity of air discharge through a delivery tube of small diameter, where it is necessary to explore the section of the tube to the very edges in order to get the mean velocity of the air, either the Pitot or the plate method is suitable. The anemometer was calibrated at Kew Observatory for speeds varying from 50 to 2,000 feet per minute; and the errors found were identical with those originally notified by the makers of the instrument. The author also made some experiments himself with the anemometer, and allowing for calibration errors found it to agree fairly well with the Pitot tube method. Mr. Bryan Donkin, to whom his thanks are also due for several suggestions, lent him a carefully made brass Pitot tube, ¼ inch internal diameter, which was fixed with its open end facing the current of air issuing from the delivery tube; the other end of the Pitot tube was connected to a U shaped water-gauge, in which the height of the column of water was read by means of a strong light and powerful magnifying glass. The dynamic pressure of the air must not be confounded with the static pressure of its compression. The dynamic pressure is due to the impact of the moving air, transmitted from the face of the Pitot tube to the surface of the water column. In obtaining the static pressure it is necessary to eliminate the effect of the velocity of the air; for in a U shaped water-gauge connected to a chamber of compressed air the static pressure is measured by the height of the column of water, which would be increased if velocity were imparted to the air so that it should impinge against the orifice of a tube connected to the gauge and facing the current. In the fans tested the static pressure was practically nil, because they were tried with free discharge and consequently at atmospheric pressure. If the face of the Pitot tube were reversed, to look in the direction towards which the current was flowing, so that the air would then act upon it by induction instead of by impact, an anomalous reading of the gauge might occur, showing zero pressure when compression was known to exist, the static pressure being neutralized by the induction of the moving air.

For each experiment anemometer readings were taken at each of the four following radii of the delivery tube:—1⅞, 5⅛, 7⅞, 10⅝ inches. As shown in Fig. 23, Plate 81, the cross section of the delivery tube was divided into four imaginary concentric rings, and each of the above radii corresponded with the centre line of one of the rings; each of the three outer rings was equal in breadth to the diameter of the anemometer. The velocity of the air in feet per minute, as ascertained at each of the four radii, was multiplied by the area of the corresponding rings in square feet; and the products being added together gave the number of cubic feet of air discharged per minute. The velocities obtained at each of the four radii are given in Tables 1 and 2 (pages 458–60) for all the fans tried. It will be noticed that the velocity varied considerably at the different radii with different fans; and no mean radius for the position of the anemometer could be obtained. The areas of the four imaginary rings, making up the total 3·141 square feet area of the tube of 2 feet diameter, were 1·275, 0·945, 0·614, and 0·307 square foot. The mean velocity of the air was obtained by dividing the air discharge in cubic feet by the 3·141 square feet area of the delivery tube. Readings of the anemometer were taken for two minutes at each of the four radii for each experiment, together with the volts, ampères, height of barometer in inches, and temperature of the air. The condition of the experimental room remained unchanged throughout the experiments, with all doors and windows shut.

Measurement of Brake Horse-Power.—The electrical motor was calibrated, so that by simply reading the ampères and noting the number of revolutions the brake horse-power was obtained. The torque or turning moment of an electrical motor is proportional to the current, and is nearly independent of the speed. A series of experiments were made with the motor running at 600 revolutions per minute, and the experimental readings are shown plotted in the diagram, Fig. 24, Plate 82. The weights on the brake in ounces are plotted as abscissae, and the ampères as ordinates; the line CC drawn through the plottings is a straight one, showing that the weights are proportional to the ampères. The readings range from the motor running light, until the resultant pull on the brake pulley was about 45 ounces. The majority of the fans were run at 600 revolutions per minute; the ampères being noted, the equivalent weight on the brake pulley was read directly off the chart, from which the brake horse-power was calculated. With a given torque the ampères were not quite constant for all speeds of the motor; they increased slightly and uniformly with increase in the number of revolutions. It was easy however to frame a formula which gave the torque at any speed the motor might be running at, taking into account the small increase in the current due to speed. The small variation of current with speed for the same torque was probably due to the variation of the skin resistance of the armature. It required 0·5 ampère just to rotate the armature, and 0·6 ampère to drive it at 600 revolutions per minute with no external load on; this current was therefore spent in overcoming the friction of the motor; and it required 0·05 ampère to drive the tachometer at 600 revolutions per minute. In finding the brake horse-power, the skin resistance of the brake pulley was allowed for, which was obtained by running the motor light with the pulley off and on successively. The power required to overcome the friction of the motor was nearly constant throughout the whole series of experiments. The motor was frequently calibrated during the experiments, and any slight variation of ampères and torque was allowed for. The ampère meter was read to one-hundredth of an ampère.

It is sometimes convenient in testing different fans to run them so that the same horse-power shall be absorbed by each. In Fig. 25, Plate 82, is drawn a curve for one-tenth of a horse-power, in which the revolutions are plotted as abscissae and the ampères as ordinates. For a particular horse-power with fans of different kinds, the torque and revolutions are varying quantities in relation to each other, though their product will be constant. In using this curve, the speed of the fans must be adjusted by the electrical resistances until the co-ordinates of the revolutions and current meet on the curve; then the motor is transmitting one-tenth of a brake horse-power. The electric motor may therefore be used as a convenient form of transmission dynamometer for testing not only fans but also other machines, the ammeter giving after calibration the power transmitted to the machine that is being tested.

Speed Characteristics of Electric Motor.—Although not essential for the present experiments, it is interesting to determine at what speeds the motor should be run so as to give maximum brake horse-power and maximum efficiency severally. Its speed characteristics are shown in Fig. 26, Plate 82, for constant electromotive force; the revolutions are plotted as abscissae, and the ordinates of electrical horse-power represent the volts multiplied by the ampères and divided by 746. The three curves show the relation between the speed, the electrical and brake horse-power, and the efficiency of the motor. They were found by the brake, the scale pan being loaded with different weights so as to produce different speeds. The brake horse-power is also plotted as ordinates at the several speeds at which the motor was run; and the ratio of the brake horse-power to the electrical is a measure of the efficiency of the motor; this ratio was calculated for all speeds at which the motor was run, and being plotted as ordinates it gives the efficiency curve. Referring to Fig. 26, it is seen that the electrical horse-power was a maximum at zero speed of the motor, and fell off with increase in the speed; the voltage or potential difference was taken at the terminals of the motor. The brake horse-power increased from zero at zero speed to a maximum of 0·14 B.H.P. at 800 revolutions per minute, after which it fell off with further increase in speed; at 1,500 revolutions per minute it had fallen to 0·07 B.H.P. The efficiency, or ratio of brake horse-power to electrical, rose from zero at zero speed to a maximum of 48·5 per cent. at about 1,200 revolutions per minute, after which it fell off rapidly with further increase in speed; at the speed of 800 revolutions per minute, which gave maximum brake horse-power, the efficiency was about 40 per cent.

Mutual Relations of Revolutions, Brake Horse-Power, and Air Discharge.—Fans 1 to 6 were tried at progressive speeds ranging from 300 to 1,000 revolutions per minute, and the following relations were verified for constant angle of blades and position of fan:—(1) air discharge varies as speed of revolution; (2) horse-power varies as (air discharge)^3. Whence follow—(3) horse-power varies as (speed of revolution)^3; (4) torque varies as (speed of revolution)^2; and also (5) torque varies as electric current. Therefore (6) electric current varies as (air discharge)^2. This last relation (6) applies to the particular motor used and to the limits of the experiments; it does not mean that all electric motors will invariably agree with it. Hence for all speeds of the same fan the ratio of air discharge to speed of revolution, and that of (air discharge)^3 to brake horse-power, are both of them constant; and putting relation (6) into a different form, the ratio of (air discharge)^2 to ampère current is also constant. The mechanical efficiency of the fan is therefore constant at all speeds within the limits of the range tried, because it varies as the cube of the air discharge and inversely as the brake horse-power. These relations apply only within the limits of speed tried, and to the particular form of fans tested; at higher speeds the air discharge will probably fall off. The experimental results of several of the fans at different speeds have been plotted, the revolutions and air discharge in Fig. 27, Plate 83, and the brake horse-power and air discharge in Fig. 28. The results for each fan have been given in the tables for one speed only, but can be found for any other speed by the above relations.

Calculation of Horse-power in Air discharged, and of Efficiencies.—Weight of one cubic foot of air at temperature t° Fahr. $= \frac{1 \cdot 3304 \times B}{T}$ lb., where B = barometer height in inches of mercury, and T = absolute temperature $= t^\circ + 461^\circ$ Fahr. Taking into account the moisture in the air, weight of one cubic foot of air $= \frac{1 \cdot 3304}{T}(B - \frac{3}{8} b)$, where b is the pressure due to the moisture in inch of mercury. If W = weight of air discharged per second in lbs., and V = velocity of air in feet per second, then kinetic energy of air discharged $= \frac{WV}{2g}$; and horse-power of air discharged $= \frac{WV^2}{2g \times 550} =$ $V^3 \times$ constant, for same fan under same conditions, which follows from relation (2) in page 446. Therefore if Q be the quantity of air discharged in cubic feet per second,

$$\text{horse-power of air discharged} = \frac{V^2 Q}{550 \times 64 \cdot 4} \times \frac{1 \cdot 3304 \times B}{T}$$
$$= \frac{V^2 QB}{T} \times 0 \cdot 00003756 \quad . \quad . \quad (7)$$

Mechanical efficiency $= \frac{\text{horse-power in air discharged}}{\text{brake horse-power}}$. Suppose the air to be flowing against the mouth of a Pitot tube connected with a water gauge, and let H = height of column of air in feet, and h = equivalent column of water in inches.

$$\text{Then } H = \frac{V^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Taking the weight of a cubic foot of water at 62° F. to be 62·35 lbs.,

$12\,H \div h = 62{\cdot}35 \div \frac{1{\cdot}3304\,B}{T}$; whence $H = \frac{62{\cdot}35\,Th}{1{\cdot}3304\,B\,12} = \frac{3{\cdot}9\,Th}{B}$. The substitution of this value for H in (8) gives $h = \frac{V^2 B}{251\,T}$. Whence substituting in (7), horse-power in air discharged $= h \times 251 \times Q \times 0{\cdot}00003756 = hQ \times 0{\cdot}00943$, from which the mechanical efficiency can then be determined.

Volumetric efficiency $= \frac{Q}{Ur^2}$, where U = velocity of tips of blades in feet per second, and r = radius of fan in feet.

Pressure efficiency $= \frac{V^2}{2U^2}$, the pressure varying as the square of the velocity.

The three efficiencies—mechanical, volumetric, and pressure—are each of them constant at all speeds with the same fan; this follows from the fact that the air discharge varies as the speed of revolution. There is great want of a recognised standard for comparing fans. Not being acquainted with any reliable experiments on the class of fans here tested, the author felt some hesitation in deciding upon the best method to employ. It may appear paradoxical that the volumetric efficiency can be greater than unity; but that the formula is based on correct principles is shown by the fact that it gives a constant efficiency for the same fan at all speeds. It was first employed, the author understands, by Professor Rateau of St. Etienne. The dynamic pressure varies as the velocity squared. The pressure efficiency varies as the square of the volumetric efficiency, both being a maximum at the same time. The pressure efficiency is not of essential importance in the fans here tested, because it is calculated only from pressure due to velocity of air, and not from compression as it would generally have to be calculated in a centrifugal fan.

Experiments with Fan Blades at different Angles.—The angles are those which the plane of the blade makes with the plane of rotation. The experimental results of fan 17 for different angles varying from 15° to 60° are given in Table 2 (page 460), and are plotted in Fig. 29, Plate 84. These may be termed the characteristic curves of the fan for varying angles, showing at a glance its general performance. The angles are plotted as abscissae; the air discharge, brake horse-power, and efficiencies as ordinates. In this example it will be noticed that the air discharge increases nearly with the angle from 15° to 30°; after which the curve rises more and more slowly until 45° is reached, and then with further increase of the angle the air discharge rapidly falls off. The brake horse-power increases with fair uniformity until an angle of 50° is reached, after which it commences to fall off, showing that the resistance of the fan is not increased by increasing the angle beyond about this inclination. The mechanical efficiency increases with the angle, and reaches the maximum of 42·8 per cent. at an angle of 27°, after which it falls off with further increase of the angle. The volumetric and pressure efficiencies increase with the angle, until they reach the maximum of 76·7 and 2·87 per cent. respectively at an angle of 45°, after which they fall off with further increase in the angle. A difficulty arises from the mechanical and volumetric efficiencies not being the maximum at the same angle. If the blades were fixed at 27°, so as to give the maximum mechanical efficiency, the volumetric and pressure efficiencies would fall to 64·3 and 2·10 per cent. respectively; if placed at 45°, so as to give the maximum volumetric and pressure efficiencies, the mechanical efficiency falls to 26·4 per cent., falling somewhat rapidly after 27° is reached. The angle of the fan blades must therefore be governed to a certain extent by the nature of the work which the fan is required to perform, and also by the kind of motor employed, whether electric, steam, or gas. In electrically driven fans, supplied with current through a meter, the mechanical efficiency may be of more importance than the volumetric, the latter varying directly as the air discharge and inversely as the revolutions and the cube of the diameter. Taking into account the combined efficiency of motor and fan, it may be advisable to modify the application of the formula for the volumetric efficiency, for the reason that it may be more economical to run the motor at a comparatively high speed; and that the required amount of air discharge would then be obtained with blades set so as to give the maximum mechanical efficiency but not the highest volumetric efficiency.

In calculating the mechanical efficiency, the power due to the friction of the motor has been excluded, so that the actual performance of the fans could be better compared, and that the results should not be affected by a factor which depends only on the state of the bearings. In Table 3 (page 461) the initial friction of the motor has been included with the brake horse-power, so that the mechanical efficiency of fans 16 and 17 may also be calculated including the friction. The mechanical, volumetric, and pressure efficiencies of fans 16 and 17 have been plotted with the friction of the motor included, in Figs. 30, 31, and 32, Plate 85. By including the friction of the motor, not only is the mechanical efficiency reduced, but also the angle of maximum mechanical efficiency is altered; for instance, the angle which gives the maximum mechanical efficiency is 30° in Fig. 30 when the friction is included, instead of 27° in Fig. 29 when no friction was included. At very small angles of the blades the horse-power of the air discharged is small, but the comparatively large friction of motor being included in the gross horse-power gives a low mechanical efficiency, which is increased as the air discharge becomes greater.

Effect of Cross Section of Fan Blades.—Seventeen three-bladed fans were tried, having blades of the sections shown in Figs. 1 to 17, Plate 79. They may be divided into four groups:—the first comprises the four fans 1 to 4 ; the second group the six fans 5 to 10 ; the third group the five fans 11 to 15 ; and the remaining two are the fans 16 and 17. The blades are of sheet iron 1-16th inch thick; with the exception of fan 10, their cross-sectional lines are all composed of straight lines or arcs of circles. The fans in each group differed from one another only in the cross section of their blades, which were flat, plano-convex, concavo-convex, of different degrees of curvature. Fan 1 had flat blades. Fan 2 was formed by fixing a circular face upon the non-propelling surface or back of the blades of fan 1, giving a plano-convex section to the blades. Fan 3 was formed by curving the blades of fan 1, so that the cross section became concavo-convex, the propelling face being concave. Fan 4 was formed by fixing upon the back or non-propelling face of the blades of fan 3 a still more convex surface, so that the cross section remained concavo-convex with the propelling face concave, but the section was not of uniform thickness. The blades of the other groups were similar in form, but of different area and thickness. In Figs. 19 and 21, Plates 80 and 81, is shown a fan of the second group in position on the spindle; the same boss and spokes were used throughout the experiments.

From Table 1 (pages 458–9) it will be seen that variation in the cross section of the blades of the fan, while retaining the same shape and area and the same conditions of trial, produced a considerable effect on the results. The first group, fans 1 to 4, were all tried with their blades at an angle of 17° to the plane of rotation, and under identical conditions. The mechanical, volumetric, and pressure efficiencies of fan 1 were 21·2 and 38·2 and 0·7 per cent. respectively. The effect of putting the curved surface upon the back of the blades in fan 2 was to increase the efficiencies to 28·0 and 54·0 and 1·4 per cent. respectively. In fan 3 with the curved blades of uniform thickness the efficiencies were all greater than those of fan 1, being 23·9 and 53·0 and 1·4 per cent. respectively; the volumetric and pressure efficiencies were about the same as for fan 2, but the mechanical efficiency was 4·1 per cent. less. Fan 4 was the most efficient of the group, the section of its blades being concavo-convex with a hollow space between the faces; the thickness of the blades on the centre line was 7-16ths inch; and the three efficiencies were respectively 28·0 and 65·0 and 2·1 per cent. The efficiencies of these fans were thus increased by making the blades thicker in the middle of their breadth. These results are in accord with those obtained in the trials mentioned in the author's former paper in 1892, which were made in order to test the effect of the thickness of the blades of model screw-propellers 14 inches diameter, rotating in a fixed position, and in air instead of in water. As then stated (page 561) "the screws were of two kinds: in one the transverse section of the blades was similar to that of an ordinary propeller, only much thicker in proportion; in the other kind the thickness was reduced to that of a thin plate, the other dimensions being identical. Screws of two, three, and six blades were tried at progressive revolutions ranging from 800 to 1,800 per minute; and it was found that the screws with the thicker blades were more efficient than those with the thinner blades." In his note to the British Association in 1893 (page 884) the author dealt with fans differing from one another only in the cross section of their blades; and the results then obtained corroborate as far as they went the experiments now described. The amount of curvature of the blades for the best effect appears to be governed somewhat by the width of the blade and the nature of the feed. With a very wide blade working in a tube, its efficiency may be reduced by thickening it, in consequence of the feed becoming thereby contracted. In the majority of cases the angles of maximum efficiency have been given in the tables. Other shapes were tried, and the general results were that the highest efficiency was obtained by making the blades as symmetrical and simple as possible. The experiments show that the backs or non-propelling faces of the blades exercise an important influence on the working of the fan, and that a curved back is more efficient than a flat one.

Fans feeding from Tips of Blades.—From all points behind the fan the air is sucked into the rarefied spaces left by the revolving blades; and is discharged in an axial direction in the shape of a cylindrical column of air having a spiral motion, the pitch of the spiral depending upon the angle at which the blades are set. Some of the fans were tried with the perimeter exposed, by moving the delivery tube 4½ inches forward, as shown dotted in Fig. 21, Plate 81, so as to increase the area of feed, the air being then drawn radially inwards from the tips of the blades, in addition to the axial feed through the spaces in the fan disc. The revolutions and air discharge of fan 9 have been plotted in Fig. 27, Plate 83, when the fan was tried in and out of the delivery tube. When out of the tube, the mechanical, volumetric, and pressure efficiencies were increased respectively from 16·9 up to 29·4, from 62·0 up to 78·0, and from 2·0 up to 3·1 per cent. In the fans arranged to feed from the tips, a much wider form of blade may be employed. It will be noticed that the general efficiency of the fans is increased by arranging them to feed from the tips in addition to the feed through the spaces in the fan disc. It is therefore important that, where possible, the fan should be fixed with its circumference exposed, which is not always done in practice.

Velocity of Air on entering and on leaving fans.—Some further experiments have recently been carried out by the author, in order to ascertain the velocity of the air at different points on entering as well as on leaving the fan. They were made with two fans of 24 inches and 48 inches diameter. The 24-inch fan, shown in Figs. 33 and 34, Plate 86, is a three-bladed fan with the blades set at an angle of 35° to the plane of rotation; it is a kind which has been designed and employed by the author for the ordinary ventilation of buildings, factories, and ships, and for drying. It was tested at 600 revolutions per minute, and was driven by a belt from a shunt-wound electric motor. Anemometer readings were taken at a distance of 18 inches in front of the fan, as well as behind. In Fig. 35, Plate 87, is shown the velocity of air in feet per minute at the different points indicated. No delivery tube was employed, the fan being entirely open in front as well as behind. The air on the delivery side, at the distance of 18 inches at which the readings were taken, had no tendency to spread beyond a radius equal to the outside radius of the fan, the velocity being zero with the anemometer placed at a radius of 13 inches, that is, one inch greater radius than the radius of the fan. The maximum axial velocity on the delivery side at 18 inches distance in front of the fan without delivery tube was 1,230 feet per minute at a radius of about 5 inches; the minimum velocity was 175 feet per minute at 12 inches radius. The velocity of the entering air was measured at points on the elliptical curve shown in Fig. 35, the axis of the anemometer being normal to the curve in all positions. The inward or radial velocity at the tips of the blades, at right angles to the fan spindle, was 250 feet per minute. The axial velocity, parallel to the fan spindle, was 303 feet per minute at a radius of $1\frac{3}{4}$ inches. The velocity of suction behind the fan depends on the distance of the anemometer from the fan disc. The stream of entering air converging towards the fan appeared to be rapidly accelerated in velocity as it approached the fan from all points behind.

The 48-inch fan, shown in Figs. 37 to 39, Plate 88, has four blades, set at an angle of $32\frac{1}{2}$° to the plane of rotation; it is designed specially for tea-drying in Ceylon and India. In order to reduce the shipping charges, it is made as light as possible; the arms carrying the fan spindle are of mild steel, 1 inch diameter, screwed into cast-iron bosses and to a cast-iron ring. The blades are hollow, of plano-convex section, made of sheet steel 1–32nd inch thick, brazed together, and riveted upon the lugs of a cast-iron boss. Though so light, the blades are so rigid as to be practically incapable of vibration; consequently the fans are nearly silent at all speeds. In Fig. 36, Plate 87, is shown the velocity of the air at different points on entering and on leaving the fan, when driven at 350 revolutions per minute. No delivery tube was employed. Anemometer readings were taken at a distance of 3 feet in front of the fan, and at the points shown on the elliptical curve behind. The inward or radial velocity at the tips of the blades was 900 feet per minute, while the axial entering velocity at a radius of 10 inches was only 540 feet per minute. The fan delivered 17,000 cubic feet of air per minute at 350 revolutions per minute, and about 34,000 cubic feet at 700 revolutions per minute.

Fan combined with Electric Motor.—In Figs. 40 and 41, Plate 89, is shown a fan combined with an electric motor specially designed for driving it. The field magnets are cylindrical, as shown in section in Fig. 42, and are made as small as possible in order to offer as little obstruction as possible to the passage of the air. In order to find the best position for the central electric motor, trials were made by fixing it both behind and in front of the fan, at different distances along the spindle. The position which offered the least obstruction to the air and gave the highest efficiency depended upon whether the fan was working with a contracted or a free orifice, and upon the amount of contraction; the best position was generally found to be at a little distance in front of the fan. There appears to be a central region immediately in front of the fan, where only a little stream of air is delivered, owing probably, in fans working with free discharge, to the centrifugal action on the front face of the blades, which is apparent near the centre.

Experiments with Contracted Outlet and Inlet.—These experiments were made with the three-bladed fan of $23\frac{3}{4}$ inches diameter, Figs. 33 and 34, Plate 86, with blades set at an angle of 35° to the plane of rotation, driven at 800 revolutions per minute by belt from a shunt-wound motor. In Figs. 43 and 44, Plate 90, the fan is shown working partly in the 24-inch delivery tube. The outer end of the tube was contracted by closing it successively with plates containing central holes of 6 and 12 and 18 inches diameter. The fan was tried both propelling and exhausting air, and its efficiency in either action was found to be much reduced by the contraction. One of the reasons that this kind of fan was unable to maintain static pressure in the air is probably the comparatively slow speed of the blades near the centre, in consequence of which the air tended to pass back again through the centre of the fan. The effect was therefore tried of fixing a circular disc in front of the fan on the delivery side, so as to prevent the air from returning through it; this had the effect of increasing the efficiency to a great extent when working against resistance, whereby a static pressure was obtained in the air delivered. Experiments were made with discs of different diameters, and it was found that the size of disc to give the best result depended upon the contraction of the delivery orifice, or upon the resistance offered to the passage of the air. Discs of 7, 10, 14, 17, and 22 inches diameter were tried for the three contractions of the orifice. The trials showed that, the more the air passage was baffled, the larger became the disc required for maximum efficiency; with free discharge the presence of the disc only reduced the efficiency. The results are given in Tables 4 and 5 (page 462). In Table 4 and Fig. 43 the fan was propelling air into the delivery tube, and the disc was placed in front of the fan in the delivery tube. In Table 5 and Fig. 44 the fan was exhausting air through the tube, and the disc was placed outside the tube but in front of the fan, which had been reversed upon its spindle. With the fan propelling air through the 6-inch orifice, Table 4, only 31 cubic feet per minute were discharged when no disc was used; and with discs of 10 and 14 and 17 inches diameter the discharge rose to 129 and 169 and 188 cubic feet respectively, the 17-inch disc giving maximum efficiency. If the volumetric efficiency of the fan without the disc be taken as 100, then with the 17-inch disc it becomes 606; while the mechanical efficiency is increased 223 times, from 100 up to 22,300. With the larger orifice of 12 inches diameter the effect was not so great: the 14-inch disc increased the volumetric efficiency 39 per cent., and the mechanical efficiency 169 per cent. With the still larger orifice of 18 inches diameter, no difference was noticed when the 7-inch disc was added; and the larger discs reduce the efficiency. Somewhat similar effects, but of less magnitude, were obtained when exhausting air instead of propelling. With the 6-inch orifice in Table 5, the 14-inch and 17-inch discs increased the volumetric efficiency 17 and 19 per cent., and the mechanical 58 and 67 per cent. The fan was also tried with the disc on the back or inlet side, and also with the central part of the blades filled up to the same extent; but the result of either plan was that the efficiency was reduced. The disc was also tried at various distances in front of the fan, and the best position was found to be when touching the blades; it then allows the fan to feed near the centre at the back, and the air in entering the fan takes a radial direction due to centrifugal action, and then passes through over the disc. In Fig. 45 is shown the probable direction of the currents of air when the fan is propelling through a contracted orifice without a disc, showing that most of the air propelled by the tips takes a short circuit and enters the fan again at the centre, being thus only circulated in the fan. In view of the fact that this kind of fan is being employed in many cases with a contracted orifice, as in Fig. 44—as when drawing air through a material to be dried, like wool, or through tortuous flues, as in refrigerating apparatus—the adoption of the central disc becomes important, inasmuch as the efficiency of the fan can thereby be increased to such a great extent.

Forced and Induced Draught.—It is interesting to notice that with a contracted orifice the efficiency of the fan is higher in exhausting than in propelling. Referring to the experiments without circular discs in Tables 4 and 5 (page 462), while 31 cubic feet of air per minute were propelled through the 6-inch orifice at 800 revolutions per minute, the delivery was increased to 451 cubic feet when exhausting, the other conditions being identical; the volumetric efficiency was increased fifteen times. With the 12-inch orifice 497 cubic feet of air per minute were discharged by propulsion, and 1,374 when exhausting, the volumetric efficiency being increased nearly three times. With still less contraction the difference was not so great, the volumetric efficiency with the 18-inch orifice being increased only from 58½ per cent. when propelling to 67 per cent. when exhausting. It thus appears that the freedom of the discharge or outlet side of the fan is of greater importance than the freedom of the suction or inlet side. As far as they go, and under the conditions under which they were made, the experiments seem to present an argument in favour of induced draught over forced.

Negative Slip, effect of thickness of blades.—It is interesting to notice the great effect of the thickness of the blades, caused by fixing the curved surface to the backs of the blades. Comparing fans 1 and 2 in Table 1 (page 458), the air discharge was increased from 2,128 cubic feet per minute in fan 1 to 2,888 cubic feet in fan 2 at 30 revolutions less per minute, merely by making the blades thicker. This is a substantial reason for the "apparent negative slip," which is sometimes noticed in a screw-propeller, when the pitch is calculated from the front face, without taking into account the round back whereby the virtual pitch is increased; and negative slip has generally been noticed in those propellers that have thick blades and round backs.

Without entering into any theoretical views as to the action of the blades, which is a complicated question affected by many conditions, it may be said that, having regard to the stream-line principle, the section of the blades should be as ship-shape as possible, and that rotary motion of the air should be as small as possible. The two losses in an air propeller are rotary motion imparted to the air, and skin friction of the blades; and the problem is to make the sum of these two losses as small as possible, and at the same time the delivery of air as large as possible. The loss due to the skin friction of the blades is comparatively small, as was ascertained by rotating the flat thin blades when their plane was set to coincide with the plane of rotation.

Note.—For convenience in making the calculations the fans have been taken at 24 inches diameter, the same as the bore of the tube. This slight difference from the exact dimensions affects the results to an extremely small extent only.

TABLE 1 (*continued on opposite page*).

Experiments on Propeller Ventilating Fans Nos. 1 *to* 10, *Plate* 79, *of* 23¾ *inches diameter, all revolving* inside *delivery air tube of* 24 *inches bore, except those marked* * *revolving* 4½ *inches* out of *tube. Blades set at angle to plane of revolution. Anemometer placed at radius of* 1⅞—5⅛—7⅞—10⅝ *inches from axis of tube.*

Number of Fan.	Angle of Blades.	Revolutions per minute.	Motor.		Velocity of Air per minute at radius				Air discharged per minute.	Weight on Brake Pulley.	Horse-Power.		Efficiency.		
			Volts.	Ampères.	1⅞	5⅛	7⅞	10⅝			Brake.	Air.	Mechanical.	Volumetric.	Pressure.
No.		Revs.	V.	A.	Feet.	Feet.	Feet.	Feet.	Cubic Ft.	Ounces.	H.P.	H.P.	P. c.	P. c.	P. c.
1	17°	890	69·7	1·50	762	767	688	607	2128	11·0	0·0158	0·0097	21·2	38·2	0·7
2	17°	860	81·5	1·92	880	917	920	930	2888	21·5	0·0866	0·0241	28·0	54·0	1·4
3	17°	645	60·0	1·58	690	730	690	675	2172	14·2	0·0430	0·0103	23·9	53·0	1·4
4	17°	525	54·5	1·58	617	713	730	615	2139	14·2	0·0350	0·0098	28·0	65·0	2·1
5	27°	610	80·0	2·33	723	804	913	951	2790	29·0	0·0829	0·0218	26·3	73·0	2·7
6	27°	490	78·3	2·53	423	690	880	903	2536	33·5	0·0770	0·0164	21·3	82·0	3·4
7	17°	758	80·8	2·07	703	785	805	760	2427	18·5	0·0650	0·0144	22·2	51·0	1·3
8	17°	650	78	2·28	645	780	805	700	2330	22·2	0·0677	0·0127	18·8	57·0	1·6
	27°	*600*	85	2·45	910	1115	1145	1050	*3385*	31·7	0·0894	0·0390	43·0	89·8	4·1
	27°	595	77	2·20	670	789	875	990	2773	26·6	0·0742	0·0214	29·9	74·0	2·8
	40°	*495*	100	2·70	735	970	1147	1070	*3265*	39·4	0·0916	0·0350	38·2	105·0	5·6
9	17°	600	69	1·91	320	365	530	635	1633	20·6	0·0590	0·0043	7·4	43·3	0·9
	27°	600	79	2·23	600	650	755	825	2348	27·3	0·0768	0·0130	16·9	62·0	2·0
	27°	*600*	86	2·47	740	890	1030	960	*2965*	32·3	0·0892	0·0262	29·4	78·0	3·1
	40°	570	88	2·75	745	810	910	960	2870	37·7	0·1075	0·0237	22·0	80·0	3·2
10	27°	*600*	81	2·31	805	930	950	930	*2891*	28·7	0·0809	0·0243	30·0	76·7	3·0
	17°	*600*	68	1·85	260	405	555	645	*1675*	19·7	0·0550	0·0047	8·5	44·4	1·0

TABLE 1 *(concluded from opposite page).*

Experiments on Propeller Ventilating Fans Nos. 11 *to* 17, *Plate* 79, *of* $23\frac{3}{4}$ *inches diameter,*
all revolving inside *delivery air tube of* 24 *inches bore, except those marked* * *revolving* $4\frac{1}{2}$ *inches* out of *tube.*
Blades set at angle to plane of revolution. Anemometer placed at radius of $1\frac{7}{8}$—$5\frac{1}{8}$—$7\frac{7}{8}$—$10\frac{3}{8}$ *inches from axis of tube.*

Number of Fan.	Angle of Blades.	Revolutions per minute.	Motor.		Velocity of Air per minute at radius				Air discharged per minute.	Weight on Brake Pulley.	Horse-Power.		Efficiency.		
			Volts.	Ampères.	$1\frac{7}{8}$	$5\frac{1}{8}$	$7\frac{7}{8}$	$10\frac{3}{8}$			Brake.	Air.	Mechanical.	Volumetric.	Pressure.
No.		Revs.	V.	A.	Feet.	Feet.	Feet.	Feet.	Cubic Ft.	Ounces.	H.P.	H.P.	P. c.	P. c.	P. c.
11	17°	850	74	1·70	640	745	850	990	2720	15·5	0·0620	0·0202	32·6	50·9	1·3
	27°	610	63	1·66	645	725	860	930	2641	16·0	0·0458	0·0185	40·4	68·9	2·4
	27°	*600*	64	1·75	765	895	870	850	*2699*	17·6	0·0489	0·0190	40·4	71·6	2·6
12	27°	600	63	1·70	590	635	740	745	2222	16·8	0·0473	0·0110	23·3	58·9	1·7
13	27°	600	74	2·06	655	745	860	995	2737	23·8	0·0671	0·0200	30·0	72·6	2·6
	17°	600	61	1·63	430	525	640	680	1926	15·3	0·0431	0·0070	16·7	51·0	1·3
14	17°	604	53	1·40	415	540	605	640	1846	10·7	0·0300	0·0063	21·0	48·6	1·2
	40°	605	85	2·40	780	940	1110	1105	3272	31·0	0·0874	0·0348	39·8	86·0	3·7
15	40°	600	84	2·40	775	965	1120	1085	3270	30·6	0·0862	0·0350	40·9	86·7	3·8
16	35°	600	65	1·77	720	780	860	830	2580	18·1	0·0510	0·0172	33·7	68·4	2·4
17	35°	600	67	1·87	685	830	920	875	2705	19·1	0·0538	0·0199	37·0	71·7	2·6

TABLE 2.

Experiments on Propeller Ventilating Fan No. 17 *with Blades set at different Angles to plane of revolution.*
Fan $23\frac{3}{4}$ *inches diameter, revolving inside delivery air tube of* 24 *inches bore; speed* 600 *revolutions per minute.*
Anemometer placed at radius of $1\frac{7}{8}$—$5\frac{1}{8}$—$7\frac{7}{8}$—$10\frac{5}{8}$ *inches from axis of tube. See Plates* 79 *and* 81.

Angle of Blades.	Motor.		Velocity of Air per minute at radius				Air discharged per minute.	Weight on Brake Pulley.	Horse-Power.		Efficiency.		
	Volts.	Am-pères.	$1\frac{7}{8}$	$5\frac{1}{8}$	$7\frac{7}{8}$	$10\frac{5}{8}$			Brake.	Air.	Mecha-nical.	Volu-metric.	Pressure.
	V.	A.	Feet.	Feet.	Feet.	Feet.	Cubic Ft.	Ounces.	H.P.	H.P.	P. c.	P. c.	P. c.
15°	40	1·05	460	470	510	510	1562	4·08	0·0115	0·0038	33·0	41·4	0·87
20°	45	1·22	570	590	610	630	1916	6·41	0·0181	0·0070	38·5	50·8	1·31
25°	52	1·36	630	680	730	770	2291	10·00	0·0282	0·0120	42·2	60·8	1·88
27°	55	1·43	640	710	790	820	2423	11·84	0·0334	0·0143	42·8	64·3	2·10
30°	60	1·66	665	770	875	860	2598	15·00	0·0423	0·0176	41·6	68·9	2·42
35°	67	1·87	685	830	920	875	2705	19·07	0·0538	0·0199	37·0	71·7	2·62
40°	76	2·12	705	855	970	900	2805	25·00	0·0707	0·0222	31·4	74·4	2·82
45°	84	2·40	780	910	960	880	2827	30·60	0·0858	0·0227	26·4	76·7	2·87
50°	91	2·59	790	880	930	870	2771	36·31	0·1024	0·0214	20·9	75·2	2·75
60°	86	2·48	210	290	450	680	1534	32·30	0·0911	0·0035	3·8	40·7	0·84

TABLE 3.

Comparison of Propeller Ventilating Fans Nos. 16 *and* 17 *with Blades set at different Angles to plane of revolution. Both Fans* 23¾ *inches diameter, revolving inside delivery air tube of* 24 *inches bore; speed* 600 *revolutions per minute. Friction of motor included. See Plate* 79.

Angle of Blades.	FAN No. 16.						FAN No. 17.					
	Air discharged per minute.	Horse-Power.		Efficiency.			Air discharged per minute.	Horse-power.		Efficiency.		
		Gross.*	Air.	Mechanical. †	Volumetric.	Pressure.		Gross.*	Air.	Mechanical. †	Volumetric.	Pressure.
	Cubic Ft.	H.P.	H.P.	P. c.	P. c.	P. c.	Cubic Ft.	H.P.	H.P.	P. c.	P. c.	P. c.
15°	1079	0·0377	0·0012	3·1	28·6	0·41	1562	0·0453	0·0038	8·3	41·4	0·87
20°	1622	0·0429	0·0042	9·7	43·0	0·94	1916	0·0519	0·0070	13·4	50·8	1·31
25°	2030	0·0521	0·0084	16·1	53·8	1·48	2291	0·0620	0·0120	19·3	60·8	1·88
27°	2185	0·0588	0·0106	18·0	58·0	1·73	2423	0·0672	0·0143	21·2	64·3	2·10
30°	2439	0·0698	0·0145	20·7	64·7	2·13	2598	0·0761	0·0176	23·1	68·9	2·42
35°	2580	0·0818	0·0172	20·2	68·4	2·39	2705	0·0876	0·0199	22·7	71·7	2·62
40°	2627	0·0958	0·0182	18·9	69·7	2·47	2805	0·1045	0·0222	21·2	74·4	2·82

* Gross Horse-Power = brake horse-power + horse-power due to friction of motor.

† Mechanical Efficiency = ratio of horse-power in air discharged to gross horse-power.

Experiments on Ventilating Fan of $23\frac{3}{4}$ inches diameter, revolving partly inside air tube of 24 inches bore.

Circular Disc fixed directly in front of fan blades, parallel to plane of rotation,
except in trials marked "none."

Outer orifice of tube contracted to 6–12–18 *inches diameter. Speed* 800 *revolutions per minute.*

TABLE 4.—*Fan Propelling air. Fig.* 43, *Plate* 90.

Diameter of Outlet.	Diameter of Disc.	Mean Velocity of Air per min.	Air discharged per minute.	Volumetric Efficiency.	Relative Efficiency.	
					Volumetric.	Mechanical.
Ins.	Ins.	Feet.	Cub. Ft.	P. c.		
6	none	160	31	0·6	100	100
6	10	660	129	2·6	416	7,190
6	14	860	169	3·4	545	16,200
6	17	960	188	3·7	606	22,300
12	none	632	497	9·8	100	100
12	7	752	591	11·8	119	168
12	10	780	612	12·2	123	187
12	14	880	691	13·7	139	269
12	17	760	597	11·9	120	173
18	none	1660	2938	58·5	100	100
18	7	1660	2938	58·5	100	100
18	10	1540	2726	54·3	93	79
18	14	1140	2018	40·2	68	32

TABLE 5.—*Fan Exhausting air. Fig.* 44, *Plate* 90.

Diameter of Inlet.	Diameter of Disc.	Mean Velocity of Air per min.	Air exhausted per minute.	Volumetric Efficiency.	Relative Efficiency.	
					Volumetric.	Mechanical.
Ins.	Ins.	Feet.	Cub. Ft.	P. c.		
6	none	2300	451	9·0	100	100
6	10	2500	490	9·7	109	128
6	14	2680	525	10·4	117	158
6	17	2730	535	10·6	119	167
6	22	2640	517	10·3	115	151
12	none	1750	1374	27·3	100	100
12	10	2000	1570	31·2	114	149
12	14	2040	1601	31·9	117	158
12	17	2040	1601	31·9	117	158
18	none	1900	3363	67·0	100	100
18	7	1875	3319	66·0	99	96
18	10	1850	3275	65·0	97	92
18	14	1830	3240	64·0	96	89

(*Read* 3 *November* 1897.)

SUPPLEMENTARY EXPERIMENTS UPON PROPELLER VENTILATING FANS.

By Mr. WILLIAM GEORGE WALKER, of London.

Since the reading of the paper on this subject at the Spring Meeting of the Institution, the author has carried out some further experiments on Propeller Ventilating Fans.

Fans with different numbers of Blades.—These experiments were made with fans of six, three, and two blades, Figs. 46 to 48, Plate 90. Each fan was 24 inches diameter; and the blades were all flat and set at an angle of 30° to the plane of rotation, and were all exactly alike in shape and area for each fan. The fans were driven at 600 revolutions per minute by belt from a shunt-wound motor. The six-bladed fan was tried first; and then its alternate blades were removed without altering the position of the fan or the angles of the remaining three blades, which was easily done by unscrewing the blades from the boss; afterwards the two-bladed fan was tried. The six-bladed fan discharged 2,350 cubic feet of air per minute, while the three and two-bladed discharged 2,535 and 2,140 respectively; their respective volumetric efficiencies were 62 and 67 and 57 per cent. These experiments show that in the fans of 24 inches diameter little or no advantage can be gained by increasing the number of blades; also that the mechanical efficiency of the three-bladed fan is the highest, the motor taking less current and the fan propelling more air than with either of the other two. The number of blades which gives maximum efficiency is probably governed by their width or area of surface; that is, the efficiency of the six-bladed fan might have been higher with smaller blade area and therefore with narrower blades. On this point reference may be made to the author's former experiments on screw-propeller surface (Proceedings 1892, page 514), which were carried out with screw-propellers $38\frac{1}{2}$ inches diameter; a two-bladed screw was first tried, and was then divided into two parts forming a four-bladed screw with blades at right angles and having exactly the same pitch and aggregate area as the two-bladed; with the four blades a very slight increase in efficiency was obtained, of only about $1\frac{1}{2}$ per cent. A three-bladed screw of the same diameter was also divided into six blades at equal angles, and only a slight increase was obtained; at the lowest speeds no gain in efficiency resulted from multiplying the number of blades. In larger fans the author has found that the number of blades may be advantageously increased.

Experiments with Helical Blades.—All the fans previously mentioned in this paper have blades with their leading and following edges in the same plane. Consequently the pitch throughout this plane is not uniform, but varies from a maximum at the tips of the blades to a minimum at their roots. The variation in the axial discharge of the air, as shown in Fig. 35, Plate 87, might therefore have been expected to be due to the varying pitch. Practically however the same variation in discharge was obtained with helical blades, that is with blades of uniform pitch. The 24-inch helical fan tried, which is shown in Figs. 49 and 50, Plate 91, was made with a uniform pitch of 3 feet, so that the angle of the tips is about 27° to the plane of rotation. The helical blades were carefully made from sheet brass 1-16th inch thick, and the true helical surface was cut on a wooden block, to which the blades were pressed until their surface coincided with that of the block. The fan was run at 600 revolutions per minute. Anemometer readings were taken at a distance of 18 inches in front of the fan. In Fig. 54, Plate 92, is shown the velocity of the air in feet per minute at the different points indicated. No delivery tube was employed, the fan being entirely open in front as well as behind; the conditions were thus the same as in the former trial described in page 453. The maximum axial velocity was 1,340 feet per minute at a radius of 5 inches, and the minimum velocity 230 feet at 12 inches radius. A great similarity will be noticed between Figs. 54 and 35, showing that the helical form of blade has not rendered the velocity of discharge more uniform than it is with flat blades.

The rotary velocity of the air was also measured at the same distance in front of the fan, by placing the face of the anemometer in the same plane as the axis of the fan. In Fig. 55, Plate 92, is shown the rotary velocity at different radii, ranging from zero velocity at zero radius to a maximum rotary velocity at 5⅛ inches radius, and falling off again at larger radii. It is interesting to notice that the maximum rotary velocity occurs at the same radius as the maximum axial velocity. The efficiency of the helical fan was increased by putting rounded backs on the blades, in the same way as with ordinary flat blades. The experiments accordingly showed that the helical blades did not possess advantages over the ordinary non-helical blades.

Negative Slip.—The apparent negative slip sometimes noticed in a screw-propeller occurs when the speed of the ship is greater than the speed of the screw-propeller, that is, greater than the product of the pitch multiplied by the revolutions, the pitch being calculated from the front or face of the blades. It has been regarded by the author in page 457 as probably due to the effect of the thickness of the blades and their round backs. On this point he has since carried out some further experiments. A three-bladed helical air-propeller was tried at 600 revolutions per minute. The angle of the tips of the blades being about 10° to the plane of rotation, the pitch was 1·1 foot, as shown in Fig. 51, Plate 91. The speed of the screw was therefore 660 feet per minute at 600 revolutions per minute; while the mean velocity of the air as measured in the delivery tube was 650 feet per minute, showing a small positive slip. The blades were of sheet brass 1-16th inch uniform thickness, so that the pitch of their back and front faces was the same. Curved backs were then slipped on, giving each blade a plano-convex section, as shown in Figs. 52 and 53. The mean velocity of the air now obtained at 600 revolutions per minute was 783 feet per minute, the air travelling 123 feet faster than the speed of the screw when the pitch is measured from the front face of the blades. The apparent negative slip was therefore 18½ per cent. With finer pitch the negative slip for thick blades was further augmented. With a coarser pitch of 3 feet, Fig. 50, the results were reversed, and a fair amount of positive slip was obtained. In screw-propellers it has been noticed that negative slip occurs when the pitch is fine; moreover for reasons of strength a screw-propeller has its blades made with rounded backs of varying thickness, so that the transverse section of the blades is nearly plano-convex. These experiments show that the phenomena and conditions of apparent negative slip in air propellers and in water propellers correspond closely; and they seem to lead to the conclusion that apparent negative slip is due to not considering the effect of the backs or non-propelling faces of the blades.

Relation of Revolutions and Air Discharge.—The law of discharge, which, as stated on page 446, was verified in the six fans numbered 1 to 6, has since been again verified with two fans of the same diameter, namely 2 feet, but more powerful as air dischargers, that is, having higher volumetric efficiencies. The measurements of the less powerful of the two new fans are shown plotted in Fig. 27, Plate 83, in which they are seen to form practically a straight line NN. At 400 revolutions 2,150 cubic feet were discharged per minute; at 600, 3,420; at 800, 4,440; at 1,000, 5,700; and at 1,200 revolutions per minute 6,790 cubic feet were discharged. The volumetric efficiencies at the respective speeds were 86·0, 90·6, 88·4, 90·8, and 90·2 per cent. These figures give a mean volumetric efficiency of 89·2 per cent. The sections of the blades were plano-convex. The second new fan, being a still more powerful air-discharger, delivering about 4,000 cubic feet at 600 revolutions per minute, followed also the same law. Thus, for the fans tested, the law seems to hold good within ordinary limits of speed, inasmuch as it is not the general practice to run a 2-foot fan above 1,200 revolutions per minute. In Figs. 56 and 57, Plate 93, is shown one of the fans arranged with a thrust bearing.

Calculation of Horse-Power and Size of Fan.—The horse-power necessary for driving the fan to produce a given discharge of air is as follows, taking the barometer at 30 inches of mercury and the air temperature at 60° Fahr., which are atmospheric conditions near enough for ordinary calculations, and the mechanical efficiency at 30 per cent. If d be the diameter of the fan in feet, a the area of the fan disc in square feet, V the velocity of the air in feet per second, and Q the quantity of air discharged in cubic feet per second :—

$$\text{Mechanical efficiency} = 0 \cdot 3 = \frac{\text{horse-power in air discharged}}{\text{horse-power to drive fan}}$$

Whence by substitution from formula (7) in page 447

$$\text{Horse-power to drive fan} = V^2Q \times 0 \cdot 00000215 \div 0 \cdot 3 \qquad (9)$$

Substituting the value of $V = \frac{Q}{a} = \frac{4Q}{\pi d^2}$

$$\text{Horse-power} = \frac{Q^3}{d^4} \times 0 \cdot 0000115. \qquad (10)$$

Taking the volumetric efficiency at 90 per cent., this for a 2-foot fan means a discharge of 3,400 cubic feet at 600 revolutions per minute, inasmuch as 3,420 cubic feet were discharged at 600 revolutions per minute by the less powerful of the two new fans tried above (page 466). Then $0 \cdot 9 = \frac{Q}{Ur^2}$ (page 448), where $U = 2\,\pi\,r \times R$ = velocity of tips of blades in feet per second, and r = radius of fan in feet, and R = revolutions per second. Hence,

$$R = \frac{Q}{0 \cdot 9 \times 2\pi r^3} = \frac{Q}{5 \cdot 7 r^3} \text{ nearly.} \qquad (11)$$

The mechanical and volumetric efficiencies here assumed may approximately be obtained with fans working under ordinary practical conditions and with free inlet and outlet.

These relations mean that for a given discharge of air the horse-power required to drive the fan varies (9) as the square of the velocity of the air ; and also that the horse-power varies (10) directly as the cube of the quantity of air discharged, and inversely as the fourth power of the diameter of the fan. With the same fan the horse-power varies (10) as the cube of the air discharge ; and the air discharge varies (11) as the speed of revolution. The height of the column of water in a water-gauge varies as the square of the velocity of the air.

The three following recommendations are therefore arrived at. First, the velocity of the air passing through a fan should be as slow as practicable. Second, the diameter of the fan should be as large as practicable. Third, the pressure of the air passing through the fan should be as small as practicable. The great feature of propeller ventilating fans is that they may be made to comply with these conditions as nearly as possible. This kind of fan is essentially a ventilator, and its principal object is to move a large volume of air at a slow velocity and at atmospheric pressure.

In order to show the great effect of the area of the fan and the velocity of the air passing through it, the horse-power has been calculated as follows for driving five fans, ranging from 2 to 4 feet diameter and each propelling 6,000 cubic feet of air per minute:—

Diameter.	Horse-power.	Velocity of Air.
2 ft.	0·72	1,910 ft. per min.
2½ ft.	0·29	1,224 ,,
3 ft.	0·14	848 ,,
3½ ft.	0·071	623 ,,
4 ft.	0·045	477 ,,

Here it is seen that the largest fan would require only 6¼ per cent. of the horse-power required by the smallest for propelling the same volume of air.

For tunnel ventilation, upon which the author was consulted by the Board of Trade and gave evidence before the Ventilation of Tunnels Committee in connection with the Metropolitan Railway, it might well be required to deliver 250,000 cubic feet of air per minute. Then employing formulæ (9) and (11) for determining the power and size for a suitable propeller fan with free inlet and free outlet, the diameter, horse-power, and speed of the fan, and the dynamic pressure and velocity of the issuing air would be severally as follows:—

Diameter.	Horse-power.	Revs. per min.	Water gauge.	Air Velocity.
10 ft.	83	348	0·65 inch	3,180 ft. p. min.
12 ft.	40	201	0·31 inch	2,214 ,,
14 ft.	22	127	0·17 inch	1,626 ,,
16 ft.	12	106	0·10 inch	1,242 ,,

The calculations for the larger fans are made on the assumption that these follow the same laws as the smaller.

It will thus be seen that, while the mechanical efficiency of a series of fans can be the same, yet their efficiency as ventilators, reckoned in volume of air moved per horse-power, can vary to a considerable extent; and a fan of high mechanical efficiency may discharge a small quantity of air per horse-power, as occurs in centrifugal fans when pressure is necessary. For example, in a test carried out by Mr. Bryan Donkin of a 2-foot centrifugal fan, with free discharge the fan delivered 1,995 cubic feet at 1,324 revolutions per minute, giving a mechanical efficiency of 5·2 per cent. and requiring 1·92 horse-power; it therefore discharged 1,039 cubic feet per minute per horse-power. When the outlet was baffled so as to give a mechanical efficiency of 40 per cent., the discharge per horse-power fell to 700 cubic feet per minute. Now an air propeller of the same diameter, tested by the author at the same speed of 1,324 revolutions per minute, moved 7,550 cubic feet per minute, and absorbed 1·4 horse-power; this is equivalent to 5,400 cubic feet per minute per horse-power. The relatively greater amount of power required for the centrifugal fan with free discharge was here due to the high velocity of the air passing through the small inlets at the centre and the small outlet of the centrifugal fan; while in the propeller fan the area of passage for the air was nearly equal to the fan disc. In the centrifugal fan there was also the greater internal loss due to skin friction. The purpose of the two fans was of course quite different: the propeller fan was for volume of air without compression, the centrifugal for volume with compression. Where the propeller fan is employed in drawing air through contracted holes or tortuous flues, the adoption of the central disc becomes important. In Table 5 (page 462) are given results of experiments with contracted inlet, and with the fan revolving partly outside the air delivery tube. The fan has since been tried completely inside the tube, and drawing air through a tortuous flue; and it has been found that, with the same power and speed of fan, the presence of a central disc of slightly conical shape increases the amount of air discharged by between 40 and 50 per cent.

The author's thanks are due to his assistants, Mr. S. G. Lovell, Mr. H. G. Woolley, and Mr. A. M. Morgan, for their help in carrying out the experiments and preparing the drawings.

Discussion, 30 *April* 1897.

Mr. Walker illustrated the paper by means of experimental apparatus which he exhibited in operation. A pair of three-bladed fans 24 inches diameter, one of them reversed to face the other, were fixed about 2½ feet apart on the same spindle, so that both ran at the same speed, and each acted to propel a current of air inwards against the other. Between them was a cardboard disc of the same diameter, loose to slide and turn freely upon the spindle. Obviously it assumed a position midway between them when they were in action, the pressure on each side of the disc being equal, because the blades of both fans were flat, and were set at the same angles, namely 20° to the plane of rotation. On now adding rounded backs upon the blades of one of the fans, giving them a plano-convex section, its power was so much increased thereby that it blew the disc away from it along the spindle, and forced it right up against the opposing unbacked fan.

On then surrounding the same fan with a short cylindrical casing, projecting about 3 inches beyond each face of the fan and just clear of the tips of the revolving blades, it was seen that the additional power gained by the rounded backs of the blades was not merely neutralised but was overpowered, so that the disc was blown back again by the opposite unbacked fan, and forced up against the encased round-backed fan. This was because the addition of the casing blocked the feeding from the tips of the blades, so that the fan could not take in so much air, and consequently could no longer discharge so much as it had done before the casing was added.

Another experiment illustrated the effect of the arrangement represented in Fig. 43, Plate 90, where a three-bladed fan of 24 inches diameter worked in one end of a delivery tube, of which the outer end was contracted by a plate containing a central outlet hole of only 6 inches diameter. A ribbon hanging in front of the outlet showed how slight, if any at all, was the issuing current of air, so long as the central portion of the fan remained open and thus allowed the air propelled into the tube to leak back again through that part, the speed of the fan at the centre being so much slower than at the tips of the blades. As soon as a loose circular disc of 18 inches diameter was placed upon the spindle, close in front of the fan, it blocked the centre of the fan and prevented this backward leakage; and the ribbon showed that the strength of the issuing current was largely increased, indicating a fair amount of static pressure in the delivery tube. If the disc was placed at a little distance in front of the fan, the pressure of the air trying to leak out backwards through the centre of the fan gradually pushed it back close up against the face of the fan.

For illustrating the rotary motion of the air discharged from the fan, the delivery tube was removed, and upon the fan spindle were placed three loose pairs of vanes, of 6 and 9 and 12 inches radius, but parallel to the spindle, so that they were not acted upon by the axial motion of the air propelled by the fan, but only by its rotary motion. The nearest pair, of 6 inches radius, was about 12 inches in front of the fan, the middle pair about 18, and the furthest about 24 inches from the fan. It was seen that, with these positions of the vanes, and at the speed at which the fan was running, the middle pair, of 9 inches radius, revolved faster than either of the others: showing clearly that somewhere in that neighbourhood there must be a maximum rotary velocity in the current of air propelled by the fan. The angle of the fan blades was 35°.

In the same experiment a row of ribbons suspended across the current, all in the same cross section at a distance of about 30 inches from the fan, showed that there was but little spread of the air radially. The air evidently issued in a cylindrical column from the fan, and preserved that form so closely that the two extreme ribbons

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on either side, hanging one inch beyond the radius of the fan, were seen only just to flutter; while those between them, being within the range of the air current, were blown forwards by its passage.

Mr. C. Humphrey Wingfield said that, while fully appreciating the great amount of labour and care which the author had expended upon these experiments, and the value of the material he had thereby accumulated for the benefit of engineers, he differed somewhat from him in the conclusions he had drawn from the experiments. In page 440 it was said that the mechanical efficiency of the ordinary centrifugal blowing fan was a maximum at a certain contraction of the outlet, which gave a certain static pressure. In a valuable paper on centrifugal fans, by Messrs. Heenan and Gilbert, read before the Institution of Civil Engineers (Proceedings 1895, vol. cxxiii, page 272), their results had been plotted in characteristic curves, somewhat similar to those now exhibited, and showing at almost every speed a maximum efficiency with a particular size of orifice; but in their experiments he could see no indication of any particular static pressure which gave a maximum efficiency. Four different diagrams were given, for different speeds and different pressures; and as the speed of the fan increased, so the efficiency increased. There was no indication of a maximum efficiency, which diminished again when the velocity was further increased. In page 440 of the present paper it was remarked that the flow of air was not assisted by any static pressure, but was due only to its velocity. There was always the pressure of the atmosphere, without which the air would hardly enter the fan at all; but as flow and velocity seemed to be convertible terms, the meaning of the remark did not appear clear.

In page 441 it was stated that the velocity of the air varied greatly in different positions in the same cross section of the delivery tube; and in Fig. 23, Plate 81, were shown four positions in which the anemometer had been placed for trying the velocity of the air. It appeared to be assumed that, all round any one of the four concentric rings there shown, the velocity was the same as at the particular point in that ring at which the anemometer had been placed. In Messrs. Heenan and Gilbert's experiments (page 279) four positions of the water-gauge had been tried, all in the same cross section of the delivery tube of 8·9 inches diameter, two near the centre and two near the outside. The air velocity varied greatly: from 118 feet per second at 3·1 inches radius on one side of the centre it fell to only 86 feet per second at the same distance on the opposite side; while at 1·1 inch radius it was 112 feet on one side and 90 feet on the opposite side of the centre. Unless therefore a great number of places had been tested in that way, there would seem to be a certain amount of assumption as to what the actual velocity was in any place at which it had not been ascertained by the anemometer.

In page 442 mention had been made of an experiment with a thin plate of small area, attached to the end of a lever: which he presumed had been only for the purpose of seeing how it would answer, as it did not appear that any results so obtained had been used for plotting the curves.

In connection with the statement in page 446 that for constant angle of blades the air discharge varied as the speed of revolution, it would be interesting to know whether it had been found that with a very high speed the air discharge per revolution fell off. It was conceivable that the fan might be driven at such a high speed that the air would not enter rapidly enough to keep the discharge up in the same proportion.

In page 448 was given a formula for the volumetric efficiency. No matter what was the contrivance dealt with, efficiency he believed always had practically the same meaning: certain theoretical assumptions were made upon which a certain maximum result could be attained, provided everything were perfect; and the efficiency was the ratio which the result actually obtained bore to this theoretical maximum result. In order that the comparison might be possible, both results must be expressed in the same terms. In the formula given for volumetric efficiency, namely $\frac{Q}{Ur^2}$, the numerator Q denoted cubic feet per second; and therefore, in order that the ratio might be a measure of efficiency, the denominator of the fraction must also be cubic feet per second. Now U denoted the velocity of the tips of the blades in feet per second, or $U = 2 \pi r \times$ revs. per second; therefore

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the denominator became $2r \times \pi r^2 \times$ revs. per second, or diameter in feet × area in square feet × revs. per second. This could not possibly represent cubic feet per second,* except in the one case where the pitch was equal to the diameter; and as it was not in the same terms as Q, the fraction did not represent at all the efficiency as defined above. It would be seen that the angle of the blades was neglected, whereas with a fan of the screw-propeller type the pitch ought to be included; otherwise it would seem as though blades parallel to the plane of revolution, and therefore with no pitch, would give the same value to the ratio, that is, would give the same efficiency, as a propeller having any pitch that might be selected. As pointed out in the paper, this ratio was due to Professor Rateau, who had given the same formula for centrifugal fans in the discussion upon Messrs. Heenan and Gilbert's paper (page 322); but it seemed as though, by there styling it the "coefficient of delivery," he had guarded himself against calling it "efficiency." It was true that in the diagram accompanying Professor Rateau's remarks (page 322) the result of applying this ratio was plotted under the name of "volumetric efficiency," together with what was called "pressure efficiency"; but as he had given a special warning that "the manometric power should not be confounded with the manometric efficiency," it seemed probable that the word "efficiency" had been placed on the diagram by mistake in both cases. By substituting the pitch for the diameter involved in U, the ratio quoted in the paper would at once become a measure of efficiency, and would be $Q \div$ (pitch × area × revs. per second). It was alleged in page 448 that the formula $Q \div Ur^2$ was shown to be based on correct principles by the fact that it gave a constant efficiency for the same fan at all speeds. But since the air discharge varied as the speed of revolution, such a formula as this could not give any other than a constant result; and even if any other dimension, such as the diameter of the fan spindle for instance, were substituted for the diameter of the fan, the efficiency so calculated would still be constant.

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* In order to obtain cubic feet per second it is necessary to multiply the area of fan disc by the velocity in a direction normal to the plane of the disc. The product of the diameter multiplied by the revolutions per second is a measure of circumferential velocity, that is, velocity in the same plane as the disc; hence it does not fulfil this essential condition.

In dealing with the angles of the blades (pages 448–9), he enquired how the angle had been measured for the curved blades: whether by a chord line across the blade, joining its lateral edges. It was always difficult to say what was the effective pitch either of flat or of curved blades like those shown in the drawings, which were not helical surfaces. If they were, the pitch would be the same everywhere, and the base of the blade would be twisted more parallel to the shaft than the tip was; but with the flat or curved blades here shown, the pitch, if it could so be called, was much less at the shaft than at the tip. The propelling action of the fan upon the air in the direction parallel to the axis was therefore slower at the centre than at the circumference: a fact which would account for the direction of circulation of the air through the fan, when working against pressure, as noted in page 455.

Allusion had been made to the fact that air entered round the edge as well as at the side of the fan (page 452). It had been pointed out by Mr. Froude, and was now generally recognised, that, with marine screw-propellers working in water, at least half the total acceleration of the water took place before it entered the propeller; and there could be no doubt that the same was equally true of air propellers of the kind described in the paper. This necessitated a convergence of the streams of air flowing towards the fan, and it might be expected that some air would enter round the edge. It was surprising however to see from Fig. 27, Plate 83, and Fig. 35, Plate 87, how large a proportion of the total air delivered was drawn in in this way. In passing through the fan the air was further accelerated, whereby a further convergence would be caused, which would be increased by the fact, previously alluded to, that less air was delivered from the centre of the fan, on account of the pitch being less there than at the circumference. The minimum axial velocity therefore of 175 feet per minute in Fig. 35 (page 453), which was measured at a radius equal to that of the fan, he thought was probably the speed of an induced current, and not of the air

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which had passed through the fan, since the latter would probably form a column of smaller diameter.

In page 456 it was pointed out that with a contracted orifice, as in Figs. 43 and 44, Plate 90, the fan was better for exhausting, as in Fig. 44, than for propelling, as in Fig. 43. One reason of its superiority for exhausting seemed to him to be that in Fig. 44 the air could not go directly through the centre of the fan, as it could through an open fan, but was here obliged to rotate with the fan; thus the centrifugal action of this part of the fan was brought into play, and being half uncovered all round the edge it could act largely in that way, in combination with the propelling action of the outer ends of the blades. In Fig. 43, where the air was going inwards round the circumference of the fan, the centrifugal action was tending to stop it from entering; the centrifugal current was crossing the entering stream, and throwing it outwards against the edge of the tube, and thereby creating an obstruction.

In relation to the vexed question of negative slip (page 457) the author's experiments were exceedingly interesting. The experiment just witnessed was conclusive as to the addition of the rounded backs upon the blades increasing the virtual pitch and the delivery. What their bearing was upon negative slip would require to be thought out. From the results of Mr. Froude's propeller experiments a table in a simple form had been published in Mr. Barnaby's book on Marine Propellers (3rd edition, Table I, page 73), from which the speaker had constructed a formula (page 64) to show, by using it in conjunction with the table, when negative slip could be produced. A number of instances had been got together, in which negative slip had been reported; and in these it had been found that the pitch was fine, and that the formula showed that the propeller ought to have negative slip. It had not been arrived at theoretically, but was simply based on the assumption that the experimental results had been correctly observed and recorded; and he had not gone further into the matter than to find a formula which should fit them. A theory however had been elucidated by Mr. Barnaby, which completely accounted for the observed phenomena of so-called negative slip.

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Mr. Walker repeated the experiments exhibited at the previous meeting (pages 470–2), showing the increased efficiency obtained by adding rounded backs upon the fan blades; and the diminution of efficiency resulting from surrounding the fan with a short cylindrical casing, so as to prevent the feeding from the tips of the blades.

On substituting a six-bladed fan of the same diameter in place of one of the three-bladed fans, it was seen that the six-bladed was somewhat less powerful than the three-bladed. A disc sliding loose upon the spindle between the two fans mounted thereon, which were blowing against each other, was seen to be blown rather further away from the three-bladed fan, instead of remaining midway between them, as it would do if they were both of equal power.

For further illustrating the effect of the arrangement represented in Fig. 43, Plate 90, where a three-bladed fan of 24 inches diameter worked in one end of a delivery tube, of which the outer end was contracted by a plate containing a central outlet hole of only 6 inches diameter (page 471), he had now prolonged the central outlet by a nozzle of 6 inches diameter and about 18 inches length, in which a small round weighted disc facing the current was carried on the short arm of a light vertical lever, whose long arm served as an index. When the fan was driven so as to propel air outwards through the nozzle, the deflection of the lever from the vertical was seen to be but slight; and a light silk ribbon suspended in front of the orifice was hardly disturbed by the issuing air. When however the driving strap was crossed, so that the fan ran at the same speed in the opposite direction, it drew air in through the same nozzle to so much greater an amount that the lever was deflected through a much larger angle on the opposite side of the vertical; and the silk ribbon was sucked right into the nozzle.

With the same apparatus was demonstrated the increased efficiency obtained by placing a loose circular disc of 18 inches diameter close in front of the centre of the fan of 24 inches diameter, whereby the air propelled forwards from the tips of the blades was prevented from escaping backwards through the centre of the fan, where the speed

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of the blades was so much slower than at their tips. If however the central disc were placed behind the fan, instead of in front, its action created a partial vacuum in the centre of the fan, and converted it into a sort of centrifugal fan. On the principle of the central disc in front of the fan, and after a long series of experiments, he had now designed a fan driven by a central motor, which was placed immediately in front of the fan so as to act the part of the central disc. This fan had a maximum efficiency of about 70 per cent. when running at the comparatively slow speed of 600 revolutions a minute. Though seemingly so small, it was really a powerful fan. The air was discharged away from the front of the fan in a cylindrical column. It would be noticed there was not much spread of the air laterally, because ribbons hung outside the line of the column remained vertical, whilst those within the line of the column were blown straight out horizontally.

The rotary velocity of the air discharged from the fan was illustrated by pairs of vanes, parallel to the fan spindle and revolving loosely upon it. The maximum rotary velocity occurred at a radius of about 5 inches with a fan of 24 inches diameter. The helical twist produced in the air as it left the fan was rendered apparent by holding in the current a long rectangular flag of light cloth, which was seen to curl itself up in a rough manner into a more or less helical surface: so that, while the inner end of the flag formed a horizontal diameter of the air current, the outer end was twisted into a vertical diameter.

Mr. M. Holroyd Smith had watched with interest the experiments just made, the author having been good enough to invite him from time to time to witness the experiments made in his laboratory. One feature about them, which had especially attracted him, would be noticed on comparing the original paper read half a year ago with the supplementary paper now read. The comparison showed that the author had advanced a step. In the first paper he had been speaking somewhat doubtfully on the question of induced versus produced currents; whereas in the second paper he now spoke much more positively. Some fifteen years ago, when investigating the action of birds' wings, he had himself been led to consider somewhat carefully the difference between produced and induced currents; and he had then come to the conclusion, which the present experiments seemed to prove correct, that the fan's principal work, almost its total work, consisted in inducing a current, and not in producing or propelling it. In the present papers one face of the fan was spoken of as the front or propelling side of the fan; and then the effect produced by making some alterations to the rear side or back of the fan was described. To himself it appeared that what was usually called the front or propelling side of the fan did very little at all, and that nearly all of the work was done from the back of the fan. Certain experiments which he had carried out, though not so extensive as the author's, were almost analogous to them. One had consisted in putting a couple of fans upon the same spindle, a few inches apart, one being driven and the other loose. If the driven fan ran in one direction so as to propel a current towards the loose fan, the latter would revolve, but slowly; if the driven fan ran in the contrary direction so as to draw an induced current from the loose fan, the latter revolved rapidly. That little experiment had led him to another, which could easily be shown on the spot, emphasizing what he should be disposed to lay down as almost universally true, namely that the back of the fan, and not the front, really did the work. On lighting a match, and striking vehemently towards it with a common Japanese hand fan, it was seen that even the most sudden approach of the fan would not blow the flame out; but on suddenly withdrawing the fan backwards away from the match, the following current of air nearly blew it out. Similarly in waving the fan quickly past the flame, if the fan were suddenly stopped just before passing the match, it produced no effect; but as soon as the edge of the fan passed beyond the match, so that the air from the back of the fan could reach it, the flame was blown out immediately. Another illustration of the same kind was afforded by supporting a piece of paper on a horizontal wire ring, and striking upwards towards it from below with the fan, whereby it was seen that no effect was produced upon the paper, which rested undisturbed upon the ring; but on holding the fan above, and then

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striking upwards away from the paper, the latter was drawn up immediately by the following current. These were some of the simple experiments which had led him to the conclusion that it was the induced and not the propelled current which represented the most effective part of the fan's work. Of the numerous sections of fan blades shown in the drawings, it had been stated in page 451 that the most efficient was the concavo-convex, Fig. 4, Plate 79, having the front or propelling face concave. Could not this result be fairly attributed to the fact that this shape represented, more closely perhaps than any other of those shown, the section of a bird's wing? It must be so, he thought, because he had found that a bird's wing had just these curves. It was the convex side of the wing that was uppermost when the bird was flying, and he believed the convex upper side of the wing had just as much efficiency in the process of flying as the concave under side. The bird had to accomplish a double act, not only sustaining itself in the air, but also propelling itself forward; and the upstroke and the downstroke of the wing were both giving the propelling force. What nature had done might safely be relied upon as being always the best; and it was a wonder that nature's example had not been followed before in the design of ventilating fans. In now following that example he was glad to see that the author was producing the remarkably good effects which he had been able to show in the experiments here exhibited.

Colonel Peyton Phelps, late R.E., though he could not discuss the reasons for the results of the experiments which had just been witnessed, was greatly interested in the whole subject, having formerly been in the Public Works Department in India, where he had had a good deal of experience in the designing, building, and ventilating of barracks; and it appeared to him that the results of the experiments now shown put a new aspect on the way in which air might be mechanically introduced into buildings. Under the old method, with the centrifugal blowing fan, the air was forced in; the current went in one straight line through the room from the point of inlet to the point of outlet, and a large space on either side was stagnant; indeed not only stagnant, but he was not sure that it did not become a reservoir for a large portion of the foul air which was inside the room, but was unable to escape. From the present experiments and paper he had gathered that the fans designed by the author enabled a large volume of air to be propelled at a low velocity; so that the probability of its being able to spread itself rapidly when it entered a room was much greater than by the old method of the centrifugal fan. There was also another point to be noticed about these experiments, with regard to the difference between induced and propelled currents. The great difficulty with powder magazines was to keep the interior atmosphere as nearly as possible at an equality with the external atmosphere; it was almost impossible to do it completely. But it occurred to him whether it would not be practicable to arrange that the propelled air discharged from one of these ventilating fans might also be accompanied by an induced current drawn out at the roof of the building: not only should the air be propelled into the inside of the magazine, but also the air should be sucked out from the top. When the warmer external air came into contact with the cool internal air of the magazine, the moisture in the warmer air must be deposited at once; if this internal air could be removed rapidly, the degree of dampness inside the magazine would be considerably diminished. From these experiments it seemed to him that this could to a certain extent be accomplished. In the vessels which were employed in the Persian Gulf, the Peninsular and Oriental steamers, and the British Indian Steam Navigation vessels, going to and from India through the great heat of the Red Sea, he could not understand why a system of ventilation worked by a fan had never been established, running round the ship and passing through all the different cabins. This he thought might be done at a comparatively trivial cost. Such an improvement in ship construction would be greatly appreciated by all who had to travel to and from India, and by all who had to pass a good deal of their service in as hot a place as the Red Sea or the Persian Gulf.

Sir Benjamin A. Dobson, Member of Council, thought the information furnished in the present papers would at any rate form

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the basis for arranging the ventilation of large buildings in the future. The question of this particular kind of propeller ventilating fan as contrasted with the centrifugal fan was highly interesting; and he hoped the author's investigations would be carried further into the action of centrifugal fans producing a propelled current. Lately he had had occasion at his own works to make himself practically acquainted with an extraordinary result. In putting up a new foundry, where each cupola was required to melt 7½ tons of metal per hour, the blast was naturally being produced by ordinary centrifugal fans. The fans were 40 inches diameter, running at 1,500 to 1,550 revolutions a minute, and had been absorbing from 28 to 30 horse-power. The last cupola put up had a 48-inch fan running at 925 to 950 revolutions per minute, which was melting the 7½ tons of metal per hour, but was taking only 10 to 12 horse-power. This extraordinary result might not have been so apparent, had it not been for the fact that at the same time a change had been effected in the driving power, by putting an electric motor to each of the fans; and then the voltmeters and the ammeters on the motors driving the fans disclosed at once the fact that one of two cupolas was doing the same work with from 10 to 12 horse-power for which the other required from 28 to 30 H.P. The result was so extraordinary that he had made a large number of experiments, and had found that the effective result of a centrifugal fan, as regarded its diameter, varied even more than the present paper had shown to be the case with these propeller ventilating fans. Enough was not yet known, he thought, about the means of moving air, either for ventilation or for blast or for any other purposes for which it was attempted to move it. The present paper he considered was one of the most interesting and valuable he had ever had the pleasure of listening to; he only hoped the investigations would be carried yet further, and that he might thus be furnished with data for explaining such an extraordinary occurrence as he had mentioned, of which in the meantime he should be happy to furnish the precise particulars.

Sir Frederick Bramwell, Bart., Past-President, mentioned that a good many years ago he had been engaged in conducting experiments which ultimately led to the introduction of the Griffiths screw into the navy. The blades of the screw were made upon the principle of an increasing pitch, increasing he believed from the leading edge to the trailing edge, somewhat as shown in Fig. 4, Plate 79. To his great surprise it was found that the leading edge of the forward or working face of the propeller blades, after it had been at work for some months, was covered with a green sea-weed, while the back of the blades, which had been thought to be doing nothing, was bright. That greatly tended to corroborate what had been shown in the present experiments. Those old experiments had also included some with a screw, the pitch of which could be varied; and it had been found that negative slip could always be obtained if the pitch were made fine: it was perfectly easy with a fine pitch of screw on a ship with full buttocks to get negative slip.

In the experiment now shown, in which a fan appeared to produce so poor a result in driving air through a tube which terminated with a flat end containing a small central outlet hole, he enquired whether the effect had been tried of terminating the tube with a conical end tapering down gradually to the size of the outlet hole.

Mr. **Edward Furness** had found that, in discharging air through a conical nozzle tapering down to the outlet orifice, the area of the outlet orifice was the sole measure of the discharge that would pass through, whatever might be the capacity of the cone. The air would not pass out any more abundantly for the nozzle being enlarged internally; it passed only as rapidly as the outlet orifice at the small end of the cone would allow. Inside the cone the air was simply deflected by the tapering walls, and formed eddies inside the conical nozzle; and it was the outlet orifice alone which determined the quantity of the air that passed through.

Mr. **Bryan Donkin**, Member of Council, desired to express his congratulations to the author, not only upon the excellent diagrams shown upon the wall, but also upon the illustrative experiments he had here exhibited with such interesting results. The paper seemed to him most exhaustive, dealing with such a

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great many experiments and facts. The quantities of air and the horse-powers had been carefully measured; and these were seldom given. The experiments had been made by varying only one factor at a time, which was so essential for generalising and for drawing proper conclusions. Having himself also made many experiments on the measurement of air, in testing about a dozen centrifugal fans,* it had occurred to him to suggest the desirability of further experiments by putting some sort of baffling diaphragm, perforated zinc or wire netting of half-inch mesh, across the whole area of the delivery tube, in order to see its effect in checking the revolving motion of the discharged air.

In testing the anemometer at Kew (page 442) it had not been stated how it was done, which was an important point. There were two ways of testing anemometers: one was by moving the anemometer in a circular path at the extremity of a long radius; and another way, which had been used in Germany, was to move it in a straight path. The latter seemed to him to be the correct method.

With regard to the question of skin friction upon the fan blades, the experiments showed conclusively how much more important a part the back of the blade played than the front; and he suggested it would be desirable for the blades to be varnished and coated with some sticky substance, so as to imitate dirty blades. If these ventilating fans were used, as they could be, for inducing draught in low factory chimneys, for instance, the blades would soon get dirty; and he should like to know the effect of the dirty surfaces on the efficiency of the fan.

As to the best number of blades, it appeared from page 463 that with fans 24 inches diameter running at 600 revolutions per minute, with two, three, and six blades, the three blades came out the best, but only about 10 per cent. better than the six blades with that particular diameter and speed. The reason of the difference he hoped the author would explain; and he imagined that if the propellers were made 4 or 5 feet diameter the effect of the number of blades might not be exactly the same as with a propeller only 2 feet diameter; but this was a question which ought to be treated experimentally.

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* Proceedings Institution of Civil Engineers, vol. cxxii, 1895, page 265.

As to the effect of the back of the blades, it would be interesting to ascertain by means of Pitot tubes the pressure not only at the front of the blades but also at the back, at different parts of the blades. There was a large field for making experiments and obtaining valuable results in this way.

Mr. J. WALTER GIBBS, Liverpool, having three or four years ago had some difficulties with fans, had been led to make a considerable number of experiments at great expense, many of which were identical with those that had been carried out by the author. With reference to the number of blades, he had certainly come to the same conclusion, namely that a large number of blades was not at all necessary; in fact the better result was obtained from the smaller number of blades. The thickness of blades was a point he had not looked into. As to the electric motors, he had dismissed altogether the idea of having an open motor, for the reason that the dust always naturally impinged upon any motor which might be used for driving a fan direct; therefore it seemed essential that the motor must be enclosed. The results of some experiments he had made in this direction had turned out satisfactorily; and it had been managed so as to get rid of any possibility of heating to an undue extent in a closed motor. There was no doubt whatever in his own mind that fans of this class should have their circumference open; his own experiments had also confirmed exactly the author's conclusions in this particular. Further still, he thought there could be no question that the effect of the fan in producing an induced draught was vastly greater than any effect it could produce in forcing the air in front of it. It was far easier to draw the air from behind by a fan of this class, which drew a large volume, than to propel a column of air in front of the fan. In regard to ship ventilation (page 481), at the present time several steamers were being fitted with fans, for the object which had been referred to. Besides the two modes already mentioned of testing anemometers (page 484), one other method which he had employed consisted in filling a closed vessel with a known volume of water, and putting the anemometer in a tube through which the air was then drawn into the vessel by allowing the water to

(Mr. J. Walter Gibbs.)

escape, thus getting the known volume of entering air registered by the anemometer. This plan he thought preferable in certainty to the swinging-bar test.

Mr. C. Humphrey Wingfield, having on the previous occasion taken exception to the adoption of the formula $\frac{Q}{Ur^2}$ for the volumetric efficiency of these disc fans, and having fully explained his reasons for so doing, need only reiterate what he had then said upon this point (pages 473–4). In the supplementary paper he noticed that the same formula had still been employed (page 467). In page 464 the great similarity between Fig. 54, Plate 92, and Fig. 35, Plate 87, had been pointed out, as showing that the helical form of blade had not rendered the velocity of discharge more uniform than it was with flat blades; and again in the next paragraph (page 465) it was said that the experiments showed that helical blades did not possess advantages over the ordinary non-helical blades. Now the angle of the flat blades at their tips was 35° to the plane of rotation (page 453), while the angle of the helical blades was only 27° (page 464), so that the flat blades had a pitch 37 per cent. greater than the helical blades. Notwithstanding this greater pitch of the flat blades, the maximum axial velocity of the air discharged from the helical blades was 1,340 feet per minute (Fig. 54), in comparison with only 1,230 feet per minute from the flat blades (Fig. 35); it was thus considerably greater in proportion to the pitch, which was the only true way of measuring volumetric efficiency. The mean axial velocity, which should preferably be compared, was not stated in the paper; but as both the maximum and minimum velocities were greater in the helical than in the flat-bladed fan, it seemed fair to assume that the mean velocity was greater also, especially in view of the great similarity pointed out (page 464) in the forms of the velocity curves, Figs. 54 and 35. The value of the rounded backs of the fan blades he thought had been fully proved by the author's experiments, which had shown clearly that the rounded backs did produce practically an increased pitch of blade, so that the virtual pitch was somewhere between the pitch of the back and that of the front. Referring to the experiment in which the motion of a hand fan, moved quickly towards a lighted match, had failed to blow it out (page 479), this was a good illustration of the fact that a flat plate moving through the open air in a direction at right angles to its surface could not disturb the air far in advance of it; and only on encountering the face of the plate did the air make its escape laterally round the edges of the plate, where a disturbance then arose by the air flowing in eddies round from the front to the back to fill up the partial vacuum created in the wake of the plate's motion. This however did not seem to him to prove in any way that an induced draught by suction would be more effective than a current propelled by pushing it in front of the fan, as the action was quite different from that of a rotary fan, which did not move along like a piston in a direction normal to the surface of its vanes, but acted partly by wedging the air out of the way and partly by centrifugal force.

Mr. Thomas Mudd, Member of Council, highly appreciated the paper and the experiments now shown, which were in many respects quite convincing. In this connection he noticed it had been remarked both by the author and by various speakers that induced draught was hereby proved to be better than forced draught. By what he thought was rather an unfortunate coincidence these two particular terms happened at the present time to be appropriated to two methods of obtaining draught for the burning of fuel in marine boilers, namely by induced draught and by forced draught. They were competitive plans, and he gathered from the paper that it was not intended in the least to deal with either of them. Having himself no interest whatever in either the one or the other, he thought in fairness to both it was desirable that any possible misapprehension should be prevented by recognising clearly that no attempt was made in the paper or experiments to prove that either method was better than the other. It appeared to him that what the paper was intended to prove was that a fan of this description drew air from the back of it better than it drove air from the front, and that it was an instrument which was not capable of producing pressure. This fact seemed

(Mr. Thomas Mudd.)

to him to be well demonstrated by one of the experiments just witnessed, in which the fan was trying to drive air through a cylindrical tube having its further end closed up except for a small central outlet hole. Here it was evident that, although the fan could get plenty of air from behind, yet, as soon as ever the cylindrical tube was filled with air at a very slight pressure indeed, the fan could drive no more air into it, because it could not produce pressure; therefore the fan could draw in no more outside air from behind, and the air which was in the cylinder would not go forward faster than a speed due to the escape through the small outlet under a very slight pressure. Naturally enough there was consequently only a small discharge from this outlet hole. But when the fan was reversed, and the air was being drawn in through this same small hole, and this was the only aperture through which it could enter the fan, while the discharge side was open to the full diameter of the fan, it seemed to him that it stood to reason the fan would draw very hard at the small hole.

There was one point that seemed worth alluding to, on the question of negative slip and the effect of the rounded backs of propeller blades. Some reference had been made to the mean between the pitch or angle of the face and the pitch or angle of the back, as explaining negative slip. Looking at the leading edge of a blade, it was readily apparent that the mean angle was less than the angle of the face, and not greater; for if L in Fig. 59, Plate 94, were the leading edge of a blade revolving about an axis XX in the direction of the arrow, and ALB were regarded as the pitch angle of the face, and ALC the same for the back, it was clear that the mean angle ALD represented a smaller pitch angle than ALB. It was evidently not by looking to the leading edge therefore that the cause of the phenomenon must be sought. Examining the trailing edge T in the same way, it would be found that the mean angle MTP was greater than the pitch angle MTN of the face. It would seem then that the effect, as of increased pitch, produced by the trailing half of the curved back of the blade, more than overcame the effect, as of diminished pitch, produced by the leading half. Another way to look at it was to regard the fluid—air or water, as the case might be—as being shot away from the blade by the face in a direction TN; while the fluid rushing in to fill up the partial vacuum formed by the movement of the blade might be regarded as travelling in a direction TO. The two currents met each other at the trailing edge T, as illustrated in Fig. 58, resulting in a mean direction TP being given to the fluid, which was equivalent to a greater pitch than that of the face of the blade, and would represent in result what was known as negative slip: that is, more effect produced than was theoretically possible when the face angle only was taken into consideration. This theory of the cause of negative slip would appear consistent with the fact pointed out by Sir Frederick Bramwell (page 483), that the phenomenon was more apparent with a finer pitch than with a coarser: as would seem clear from a comparison of Figs. 59 and 60. The angle NTO between the face and the tangent to the back of the blade would be constant for any setting of the blade; and the half of it forming the increment, namely NTP, constituted a much larger percentage of increment at the trailing edge over the face angle MTN with the finer pitch shown in Fig. 60 than with the coarser pitch shown in Fig. 59. This condition favoured the result being more felt with a finer pitch than with a coarser. The fact of the increase of pitch at the trailing edge overcoming the diminution of pitch at the leading edge—probably due to the fluid having acquired velocity when passing the trailing edge which it had not acquired when passing the leading edge—would point to the conclusion that in designing a propeller it was of greater importance to study the form of the section and the sharpness of the edge for the trailing half of the blade than for the leading half.

Mr. David Joy said his experience had led him during most of his life to look more or less closely into the relative merits of induced draught and forced draught; and he was greatly mistaken if the forced draught at present used in the stoke-holds of ships could at all compare with the induced draught of the existing locomotive. The finest draught he knew of anywhere, as every locomotive superintendent would agree, was the exhaust or induced draught of the locomotive.

Mr. Walker said the concavo-convex section of the blade shown in Fig. 4, Plate 79, which Mr. Holroyd Smith had pointed out was somewhat approaching the section of a bird's wing (page 480), had certainly given very good results indeed, and had been utilised in the propeller ventilating fan. Nevertheless it could not yet be definitely said which was the best section, because a long course of experimenting was still required, in order to arrive at what was really the best section. So far as the experiments had gone, they certainly seemed to show that the face of the blade should be slightly concave, and the back of the blade should be considerably more convex.

The drying of powder magazines (page 481) was a matter of great practical difficulty. Theoretically it was simply a question of the dew-point. The great aim was to keep the temperature inside the magazine equal to the temperature outside. If these two temperatures could be kept equal, there would be no condensation when the doors were opened. The great difficulty was to keep these temperatures equal, whether constant or not; and certainly it would be interesting to try what could be accomplished in this direction by means of artificial ventilation.

In corroboration of Sir Frederick Bramwell's experience with the Griffiths screw (page 483), in his former paper in 1892 he had drawn attention to the fact (page 523) that in a screw-propeller 10 feet diameter, after some five or six months' voyaging to the Mediterranean, certain portions of the faces of the blades were covered with seaweed some inches long. The greater part of the backs of the blades was also covered with grass.

As to whether the efficiency would be increased by putting on a cone at the end of the delivery tube, instead of closing it with a flat end having a small central outlet hole (page 483), he had not yet carried out any experiments, except only a rough one with a cardboard cone. Where the velocity was high, he was under the impression that the efficiency was increased by the adoption of the cone; but to what extent he was unable as yet to say.

The method that he had used for baffling the outlet of the discharged air was far from uniform, consisting merely of a plate with a circular hole in the centre, placed at right angles to the axis of the current. On Mr. Donkin's suggestion (page 484) he had tried a perforated-zinc plate, in which the perforations were spread over an area equal to the fan disc, instead of a single central hole equal to the sum of the perforations; thus the baffling was more uniform, and somewhat better results were obtained than with the single central hole.

The method of testing the anemometer at Kew (page 484) was simply by placing it at the end of a rod, and whirling it round in a circle. That was really a most unsatisfactory method, but it was the best that he could get in this country for calibrating the anemometer. The mode of testing an anemometer by allowing a known quantity of water to flow out of a vessel (page 485) would cause a varying velocity of the air, due to the varying head of water in the vessel and the consequent varying velocity of outflow. In testing anemometers it was necessary that the velocity of the air should be constant throughout each individual test. It would therefore be better he thought to start with the measuring tank empty, and to fill it at a constant rate from another tank, thereby forcing the air out at a uniform velocity through the anemometer.

Why a six-bladed fan was less efficient than a three-bladed (page 484) was rather a difficult question, which he was not yet able to answer with any certainty. In the six-bladed fan he was inclined to think the blades worked too closely in the wake of one another at the high speed at which the fan revolved: so that the alternate blades worked almost in a partial vacuum left by the other blades.

The fact of Messrs. Heenan and Gilbert's experiments on centrifugal fans showing at almost every speed a maximum efficiency with a particular size of orifice (page 472) seemed to him to coincide exactly with the statement in page 440, instead of differing from it. The remark that there was always the pressure of the atmosphere to assist the motion of the air did not apply, he thought, to ordinary propeller fans working at atmospheric pressure, where the onward motion of the air from the fan was due only to propulsive energy; being at atmospheric pressure, its flow obviously could not be assisted by the atmosphere.

(Mr. Walker.)

The velocity of the air was nearly uniform (page 472) all round any one of the four imaginary concentric rings shown in Fig. 23, Plate 81, although it varied considerably in the different rings.

In confirmation of the law that the air discharge varied as the speed of revolution (page 473), he had tried powerful fans up to 1,200 revolutions per minute, and at this speed no falling off was noticed in the air discharge per revolution.

To the volumetric formula $\frac{Q}{Ur^2}$ in page 448 objection had been taken by Mr. Wingfield (pages 473–4) on the ground that, as the numerator was in cubic feet, the denominator ought also to be in cubic feet. The latter requirement he considered was already complied with, because the velocity of the tips of the blades in feet was here multiplied by the area in square feet. The accidental coincidence that the velocity was in this particular fan a rotary velocity in the plane of the area did not in his opinion affect the value of the formula at all, as he considered it was quite legitimate to deal with velocities in different directions: just as was done in transforming the rectilinear velocity of a steam-engine piston into the rotary velocity of the crank. As to the suggestion (page 474) that the pitch ought to have been included in the formula for the volumetric efficiency, it appeared to him that it would not be convenient to include the pitch. In the first place it was difficult to say what the pitch was in these fans; and in the next place it would have to be settled whether the maximum pitch should be taken, or the mean pitch. Again there seemed no reason why, if the pitch were included, the formula should not include also the area and shape of the blades, whereby it would become considerably complicated. The volumetric formula was almost of more value for finding the dimensions of a fan than it was as a measure of efficiency; and it had a great advantage he considered in not being governed by a doubtful quantity like the pitch.

The fact that the formula constructed by Mr. Wingfield from Mr. R. E. Froude's experiments showed that when the pitch was fine the screws should have negative slip (page 476) was the natural consequence of Mr. Froude's model experiments having been made with blades having rounded backs: so that, when the pitch was measured from the front face, negative slip might be expected to occur through not taking the rounded backs into account; and those experiments corroborated his own.

The statement in page 465 that helical blades did not possess advantages over non-helical (page 486) was meant to apply only to the particular experiments in pages 464–5, in which the helical blades had not rendered the velocity of discharge more uniform than it was with flat blades. Mr. Wingfield's comparison of pitch (page 486) was derived from only one form of flat blade, for which the pitch had been taken from the angle at the tips of the flat blades; but the mean pitch of the flat blade came out less than that of the helical: so that it seemed hardly correct to say that the pitch of the flat blade was 37 per cent. greater than of the helical.

With Mr. Mudd's important remark as to forced and induced draught (page 487) he entirely concurred. It was true that the particular experiments which he had been making showed that for induced draught these propeller ventilating fans were more efficient than for forced draught. But as to induced draught being always more efficient than forced draught, he had not made any such remark, because he had not carried out a sufficient number of experiments to justify such an opinion.

The PRESIDENT considered Mr. Walker's original and supplementary papers had proved both valuable and interesting; and they had raised a discussion which was also characterised by the same qualities. He was sure therefore that the members would accord to him a hearty vote of thanks.

Dr. J. S. HALDANE, Oxford, wrote that, as a member of the Board of Trade Committee on the Ventilation of Metropolitan Tunnels, he had recently had to consider carefully the effects capable of being produced by fans or other ventilating appliances, when used to extract large volumes of air against slight resistances. In short

(Dr. J. S. Haldane.)

lengths of tunnel, such as those on the Metropolitan Railway, the resistance in the tunnel itself, when about 240,000 cubic feet of air per minute were being extracted, would be only about 0·02 inch of water, or 0·1 lb. per square foot (see Report of the Committee, appendix 1). This was only about 1–100th of the resistance ordinarily met with in the ventilation of mines, and in similar cases where a large volume of air had to be drawn through comparatively long and narrow passages with irregular walls; consequently the problem of tunnel ventilation was in many respects different from that of mine ventilation. In particular the work expended in simply passing the air through the fan itself and through its inlet and outlet passages came to be of the utmost importance. Thus, to take an example, he had calculated that, in one of the centrifugal fans referred to before the Committee, only about 1–10,000th part of the horse-power expended in driving the fan was applied in moving the air in the tunnel itself, the remainder of the power being absorbed in simply passing the air through the fan and the ducts immediately connected with it.

It appeared to him that the present paper had furnished new and valuable data with respect to the economical application of fans to the extraction of large volumes of air against low resistances, as in the ventilation of comparatively short tunnels and in many similar cases. The experimental data hitherto published as to the action of fans seemed all to have been obtained with reference to resistances of an inch or more of water. The action of fans or other appliances working against low resistances had been strangely neglected or avoided by engineers. It was a great step forward, he considered, to have now on record definite quantitative data, which showed clearly that the internal resistance of a fan could be reduced almost indefinitely without impairing its efficiency: so that, by means of properly designed and properly applied propeller fans, enormous volumes of air could be extracted against low resistances with a trifling expenditure of work. He should like to ask the author whether he thought it would be worth while to carry out some further experiments as to the effect which would be produced on the mechanical efficiency of his experimental fan by making the inlet or outlet of the tube funnel-shaped. Judging from the experiments described by Peclet (Traité de la Chaleur, vol. 1, book 2, chap. 4), the shape of the inlet and outlet would have a great influence on the work absorbed in passing the air through the tube. If the waste of energy due to the abrupt inlet or outlet were avoided, it would be possible to make a fairer comparison between the mechanical efficiencies of propeller and centrifugal fans.

Mr. R. **Edmund Froude** wrote that he thought the author was perfectly right about the rounding of the backs of the blades conducing to apparent negative slip by increasing the effective pitch, for that was what it came to. At the Admiralty Experiment Works, Gosport, experiments on model screw-propellers in water had shown that, in a blade of parallel thickness, hollowing the face of the blade gave an effective pitch greater than the mean pitch; and that rounding the back, while the face remained a true helix, had the same effect. The model screws used in the experiments whence Mr. Barnaby's tables had been derived were of ordinary type, with true helical face and round back; the thickness to scale was much the same as in full-size bronze propellers. The point however was so much a side issue in the present paper, that he did not think it worth while to remark on it further in this connection.

Mr. **Hiram S. Maxim** wrote that, before commencing his flying-machine experiments at Baldwyn's Park, he had endeavoured to obtain some information in regard to the action of screw propellers working in the air. He went to Paris and saw the apparatus employed by the French government for testing the efficiency of screw propellers; but the propellers tested were so badly made that the tests were of no value. An English experimenter who professed to have made a life-long study of the subject had assured him that the screw propeller would be found inefficient and wasteful of power, because it had a strong fan-blower action, drawing air in at the centre and discharging it with great force at the circumference. Most of the data and formulæ he had been able to meet with were so confusing and contradictory as to be of no value

(Mr. Hiram S. Maxim.)

whatsoever. In computing the thrust of a screw, some experimenters were of opinion that the projected area of the blades should alone be considered; and that the thrust would be equal to a wind blowing against a normal plane of equal area to the blades at a velocity equal to the slip. Others thought the whole screw disc would have to be considered: that is, that the thrust would be equal to a wind blowing against a normal plane equal to the area of the whole disc at the velocity of the slip. The total projected area of the blades of the two screws in his large flying machine was 94 square feet, and the joint area of the two screw discs was 500 square feet. By the first mode of calculating therefore, the screw thrust of the machine, when running at 40 miles an hour with a slip of 18 miles an hour, would have been, according to the well known formula, $18^2 \times 0 \cdot 005 \times 94 = 152$ lbs. If however, by the second method, the whole screw disc were considered, it would have been $18^2 \times 0 \cdot 005 \times 500 = 810$ lbs. When the machine was run over the track at this rate of 40 miles an hour, the thrust was found to be rather more than 2,000 lbs. When the machine was secured to the track and the screws revolved at such a speed that the pitch in feet multiplied by the turns per minute was equal to 68 miles an hour, the thrust was found to be 2,164 lbs. In this case the motion was of course all slip; and after the screws had made a few turns, they had established a steady air-current, and the power exerted by the engines was simply spent in maintaining this current; and it was interesting to note that, if computed from the projected area of the blades by the same formula, the thrust would now be $68^2 \times 0 \cdot 005 \times 94 = 2{,}173$ lbs., which was almost exactly the observed thrust. Hence it would appear that, when the machine was stationary and all the power was consumed in slip, only the projected area of the screw blades should be considered. But whenever the machine was allowed to advance and to encounter new air, the inertia of which had not been disturbed, he had found that the efficiency increased in geometrical progression. The exact rate of this progression for all speeds he had not yet ascertained. His experiments however had shown that, with a speed of 40 miles an hour and a slip of 18 miles an hour, a well made screw-propeller was thirteen times as efficient as had been supposed by early experimenters.

Mr. Basil H. Joy wrote, in reference to the apparently greater power of the induced side of a current of air than of the discharge side, that some small experiments with which he had been connected would seem almost to point to the opposite conclusion: although he quite appreciated the fact that the two cases were not parallel, because the source of power was different in each. In his own experiments the current of air was obtained by means of a jet of water from an ordinary house supply, which by passing through a special shape of rose or spray nozzle was spread out so as to form a sort of water piston that completely filled the bore of a vertical tube of about 5 inches diameter. The effect of this piston was to induce a powerful current of air down the tube, which affected the flame of a candle held at a distance of about 8 feet from the orifice of a horizontal discharge bend at bottom; but when the candle was held in front of the suction inlet at top, the flame was not affected at a distance of more than about 2½ feet, at which distance it would be blown out at the discharge outlet.

Mr. Walker quite agreed with the remarks of Dr. Haldane (pages 493–5) as to the small amount of power necessary for the ventilation of tunnels, in comparison with that required for mines. As suggested, he intended carrying out some experiments with funnel-shaped inlet and outlet. Where expansion or contraction of air took place, as in centrifugal fans, a funnel-shaped outlet, allowing of a more uniform expansion of the air from the fan down to the pressure of the atmosphere, would tend he thought to increase the mechanical efficiency. An air propeller generally worked at atmospheric pressure, and the air was sucked in from all points behind the fan at a nearly uniform rate, and in the form of an imaginary cone. Having thus far measured the discharge when it took place through a cylindrical tube, he purposed replacing the cylindrical by a funnel-shaped tube of equal length, in order to find out what effect would thereby be produced upon the mechanical efficiency.

The view that the rounding of the backs of the blades conduced to apparent negative slip was corroborated by Mr. Froude's remarks (page 495).

(Mr. Walker.)

Referring to Mr. Maxim's experiments (pages 495–6), he had himself arrived theoretically at the following formulæ:—thrust = (revolutions R per minute)^2 × (diameter)^4 × constant C; horse-power to drive propeller = R^3 × (diameter)^5 × C; also for the same propeller, thrust = $R^2 C$, and horse-power = $R^3 C$. His own experiments showed that the thrust varied actually as the square of the revolutions per minute, and nearly as the fourth power of the diameter; in these particular experiments the propellers were not precisely similar, which might account for the thrust not varying precisely as the fourth power of the diameter.

In Mr. Basil H. Joy's experiment the air would be sucked into the inlet from all points behind in a uniform manner and in the shape of an imaginary cone, which would account for the small effect on the candle at 2½ feet distance from the inlet. At the outlet the effect was quite different, because the air would be discharged straight forwards in a cylindrical column, and would retain its velocity for some considerable distance. Had the candle been placed quite close to the inlet and to the outlet, the wind would have had the same effect on the flame in each position, because the same quantity of air was entering at the inlet that was leaving at the outlet. If any conclusion could be drawn from the experiment, it would be in favour of induced draught, by showing that the feed could spread itself all round over a larger area, thereby producing a smaller velocity of current at a shorter distance from the inlet; and this smaller velocity for the same amount of feed was naturally conducive to increased efficiency, and the principle was somewhat similar to that of the expanding or conical chimney often employed on the outlet of centrifugal ventilating fans.

DIAGRAM ACCOUNTS FOR ENGINEERING WORK.

By Mr. JOHN JAMESON, of Newcastle-on-Tyne.

In engineering establishments few things are of more importance than a ready and accurate system of Prime Cost Accounts. By promptness and accuracy in ascertaining cost, the net result on the completion of every contract or piece of work done is at once brought clearly before the management; and the profit or loss shown serves as a guide for the acceptance or rejection of other contracts or other work. Usually the elimination of unprofitable orders and the cultivation of profitable work, directed by actual knowledge of cost, are alone more than sufficient to justify the comparatively small expenditure involved. The requisites of a good cost system may be summarised as follows; and they form the foundation of such a plan of Diagram Accounts as it is the purpose of the present paper to describe.

Firstly, costs should always be posted closely up to date. The requisite data are practically complete at the close of every day's work. They should therefore be posted under all their subdivided heads not later than the next day. The posting is more easily done the next day than at any subsequent time; and mistakes promptly discovered may be corrected with far less trouble and loss of time than if a week has elapsed since their occurrence.

Secondly, the system should be one of balance. The total wages and total store issues and incidental expenses should balance the prime cost of all the work done for customers, for repair and maintenance, and for improvement or extension; and each of these items should be quite distinct by itself.

Thirdly, it should indicate at a glance probability of error, if error exists; and much may be done in this way, in regard both to labour and to store issues. The ability to detect errors is of far more value than the mere correction of an individual error as it occurs. The occasional discovery of error by a process probably unknown except in the office, or even the occasional demand for an explanation of deviations from ordinary practice, produces a degree of care and a habit of accuracy in making the primary returns, which is a great benefit in itself, and which without such help it is difficult to secure.

Fourthly, a charge should be included for the use of every machine employed. Work which involves the use of costly machinery should not be simply compared with other work involving perhaps equal labour but not requiring the same use of machinery. The capital value of the machine, its depreciation, the power required to drive it, and the space it occupies in the shop, are all elements of cost, which should be apportioned with careful consideration of their incidence. Moreover machine time-boards present the further advantage of showing whether the machinery has been kept fairly employed while there was work suited for it to do. It can also be seen what class of machines may be deficient in number, as compared with other classes. The machinery employment diagram, Fig. 1, Plate 95, shows the percentage of the actual earnings of each class of machines, compared with their possible earnings. The straight line at top representing 100, it is seen that the lathes, indicated by the uppermost of the fluctuating lines, average here nearly 95 per cent. of their possible earnings; next below come the boring machines at about 70 per cent.; and lowest are the planing machines, averaging less than 50 per cent. of what they might do in full work.

Fifthly, manufacturing and commercial trading should be kept distinct. If certain work is to get the benefit of good purchases in a rising market, and other work to be handicapped by bad purchases in a falling market, an element is introduced into the costs which should not exist therein; variation and confusion are produced in what ought to be uniform and simple. Trading profits or losses should be confined to the commercial books; manufacturing profits or losses alone should be entered into the cost books.

Since the introduction of the steam-engine indicator the performances of engines have been exhibited diagrammatically; and from the indicator diagram the horse-power is reckoned out in figures. But for enabling engineers to judge of their economy, the form of the drawn diagram is of greater importance than the arithmetical figures deduced therefrom. The diagram reveals at one view the whole performance; and upon it may be superposed a theoretically perfect diagram, bringing out every deviation and its effect. Precisely what an indicator diagram does in exhibiting the performance of a steam engine, a set of properly constructed account diagrams will do in disclosing the economic working of a manufacturing concern, in all that pertains to the actual manufacturing costs.

From the several lines of an account diagram adequately filled up may be deduced a closely approximate single line pointing directly to a graduated scale of greater or less profit or loss. Waiting till the close of the year for a balance sheet, produced too late for practical effect, is by no means a satisfactory course; the balance of profit or loss at the year's end is merely an aggregate of items arising day by day. If the exact tendency of this aggregation is displayed day by day or at short intervals, for the guidance of the management, a most important advance is realised.

The varying results of five or ten years' work can be exhibited upon a single sheet in a few lines, the direction of which indicates their import. Thus the diagram, Fig. 2, Plate 95, presents a review of nine years' work, in which the top fluctuating line UU indicates the actual invoice price of the output, when corrected for variations in rate of wages, in price of materials, and in outward selling prices. Replacing this fluctuating line by a horizontal straight line denoting 100, the percentages which the several charges bear to the output are plotted from the zero or base line: namely the machinery charges MM, the establishment charges EE, the wages WW, and the stores issues SS. The sum of these added together gives the line TT of total costs; and the interval between this line and the straight line denoting 100 represents the percentage of profit where below the straight output-line, and the percentage of loss where the total costs exceed the output, as they are here seen to do in the fourth and fifth years. Not only does such a review furnish data of great value for comparison with present operations, but it fixes in the mind broad general principles of practical importance in regulating future work.

In some exceptional cases these principles seem opposed to what appear to be the most obvious economic considerations. For instance, on a particular contract a heavy loss had been sustained in a bad year. Under such circumstances the first thought would naturally be that such a contract should be avoided in the future. When however the year's accounts were thrown into diagram form, and a comparison of results was instituted, it became at once apparent that without this losing contract the bad year's loss would actually have been increased. An illustration of the possibility of such an occurrence is shown in the diagram, Fig. 3, Plate 96. Here the line UU represents the invoice price of the output, and TT the total costs including establishment charges. The proportion of establishment charges absorbed by each contract is shown by the line AA; and the apparent profit or loss shown by the cost books is plotted in the line LP. A circle drawn from the datum line at the first contract and again at the fifth shows the relation which the charges absorbed bear to the apparent loss on each of these contracts; and discloses the fact that, while an absolute loss was sustained on the first contract, a relative loss only was incurred on the fifth, on which the establishment charges bore a larger proportion to the whole. That is to say, in the absence of this fifth contract the establishment charges absorbed by it would to a large extent have fallen upon the other contracts, diminishing the profit or increasing the loss on each, and resulting in a worse total for the year than that produced when the fifth contract is included.

If a case could exist in which the profits of manufacturing some special article were approximately uniform, manifestly the absolute amount of profit would depend on the output of work; but then, the sunk capital being a fixed quantity, the rate of profit would obviously not be uniform. Similarly it might perhaps be imagined that, if half the normal quantity of work be done, an approximation to accuracy of estimate might be obtained by doubling the proportion of the fixed charges for rent, rates, insurance, depreciation, salaries, and other incidental expenses; but almost any one who has not made a special study of the matter would be surprised to find how wide of the mark such an estimate would be. The following illustration is derived from facts of actual experience. In successive periods of abundance and slackness of work, where the work and management continued of the same character, less than £30 of wages usually completed £100 of finished work in the brisk times, as shown for the first period plotted in Fig. 4, Plate 96. Here the actual invoice price of the output is indicated by the line UU; and replacing it by the horizontal straight line marked 100, the line WW is plotted to represent the percentage of wages on output. The vertical scale for the output has been altered, and the years have been transposed and combined, so as to get a continuously falling line for the output; and corrections have also been made for varying conditions. The wages line WW is then a continuously rising line, until in the slackest period the wages were more than doubled for the same value of output, while the rate paid per man in the slackest period was actually less than in the busiest. In other words, in the same factory and under practically the same conditions a workman turned out five finished articles at higher prices when there was plenty of work, as against little more than half the quantity at lower prices when work was slack. In the latter case loss is almost inevitable.

In this connection there is one consideration which must not be lost sight of: namely, that the percentage of labour cost to the total cost of finished work is dependent both on the wages paid and on the works charges and on the store issues; and that the percentage of the works charges is diminished in brisk times, while that of the store issues may be considerably increased. For instance, it is possible to buy forgings either finished or rough. With abundance of work in hand it may be expedient to buy in as finished a state as possible; and in slack times to do all possible work in one's own shop. The effect is to pass through the store issues to finished-work account a high-priced article when bought in the finished state, and the same article at a low price when bought in the rough; and thus to disturb the percentage of labour. Having examined individual cases however, the author is satisfied that this consideration by no means accounts for the discrepancy pointed out. To what extent the latter may be explained by the supposition that workmen do not like to complete a job without prospect of more to follow—or how far it may arise from the necessity, when there is little work, for more change of job, by employing a man upon a variety of work instead of continuously upon one kind; or how far the mere emptiness of the shop may give increased opportunity for skulking; or how far disheartening influences may unconsciously sap normal energy—it is perhaps both hopeless and useless to enquire. Under these circumstances it may probably be hopeless to ask for higher prices; but it is worse than hopeless, it is ruinous, to attempt to reduce loss by restriction of output. The remedy, whether practicable or not, would lie in the opposite direction. At all times therefore it is of the highest importance that the manager should have before him in the most simple and intelligible form the facts which day by day go to form an aggregate of prosperity or adversity. Before even the best management can have any chance of success, there must be provided an adequate supply of work to do reasonable justice towards the sunk capital and the staff. If the supply of work be inadequate, and therefore unfair in this respect, no management can prevent disaster. If the manager be an expert book-keeper and devote a good deal of time to the study of the books, he may acquire all the knowledge which can be embodied in a diagram. But a clerk once instructed in the method of procedure would probably in most cases produce more expeditiously, more correctly, and much more cheaply, a diagram containing all the information in the best form. The author's idea is to present to the management, with the utmost clearness and the least possible trouble, an exact record of progress in any desired detail.

One other advantage in a good series of diagram accounts extending over a period of years lies in its showing that extreme over-pressure of work is too costly; extreme deficiency of work is ruinous; between them somewhere lies a mean, at which the highest profit may be made. It is important therefore that this mean should be ascertained, and then that it should at all times be as nearly as possible maintained. Good management should be judged, not by the mere profit made, but by the profit viewed in the light of the favourable or adverse circumstances under which it has been made. Moreover when the capacity of works for profit-making has been ascertained by the review of past operations, the practical result of each year should be gauged, not so much by the percentage gained on capital, which is the ordinary gauge, but by the result which past experience has proved the works are capable of producing. That is to say, if £30,000 can be gained in a typical year and only £20,000 has been gained in a particular year, there has been in this year, whether brought out in figures or not, a loss of £10,000, which would be shown in such a diagram as Fig. 2, Plate 95, if one extra line were added.

The facts which apply to the general conduct of works apply in different degrees to all the separate departments in which profit or loss may be made. In many cases it would doubtless be found advantageous to construct diagrams of departments, so as to show what each department is doing towards the general result, and also to show from time to time its own progress towards economy or towards increased expenditure. In Fig. 6, Plate 98, for instance, is shown a diagram of the actual consumption of water in a factory on Tyneside during the four years 1893–6. The water account being kept in this diagram form, attention was at once drawn to the great rise in the second and third quarters of 1895, thus leading to an investigation which disclosed a serious leakage due to two broken pipes, whereby for the third quarter of the year 19,700 gallons were escaping daily through a neighbouring drain pipe. The discovery and stoppage of the first leak produced the first fall in the diagram; but as the consumption was still too high, the pipes were further laid bare, and the second leak was then discovered and stopped. The improbability of the loss of water being detected by the mere payment of the water account was here increased by the fact that the turnover of the firm contributing this diagram exceeds £700,000 a year.

In Fig. 5, Plate 97, is shown a diagram representing the plotting of twenty-nine out of a hundred consecutive orders executed in a foundry. These have been selected and arranged, simply so as to get the line of invoice prices to fall continuously from left to right, as shown by the descending stepped profile; and also to omit orders which were too small in amount to be plotted clearly on the scale of the diagram. The cost line, also stepped and mainly falling in the same direction, is not continuously descending, but occasionally rises. The space between the two lines represents the apparent profit, exclusive of establishment charges. The diagram in this form is considered by the author to be a readier guide for revealing anomalous results than a double array of figures would be. For illustration only, the wavy line XX is plotted separately, representing the percentage which the apparent profit forms of the costs, apart from establishment charges; and in the lower line YY the establishment charges are distributed in proportion to the costs. It is seen that this lower line YY is not parallel to the upper line XX; but the lower line YY represents the accurate results of the work done, and this line it should be the duty of the cost clerk to present to the management at short intervals. In two instances within the author's knowledge surprising results have arisen from working out this line, showing unexpected and considerable differences between tariff rates for various classes of castings and their actual costs.

Discussion.

The PRESIDENT said that the present paper was somewhat out of the usual course of those read and discussed at this Institution. It would no doubt be considered valuable and useful, especially where employers were really the masters of their own workshops. Naturally it had not taken into consideration the labour disturbances which had occurred in this country since it was written; and he was afraid it would be found that all the calculations it dealt with would be more or less upset, and of little value to manufacturers and engineers at large, unless they remained masters of their own businesses.

Mr. DAVID JOY, while not prepared to discuss the details of the paper, recalled that some years ago, when acting as secretary of the Barrow Shipbuilding Company, which even then was a firm of no small magnitude, he had been rallied by the managing director, the late Sir James Ramsden, upon occupying such a position after having been all his life an engineer. His answer had been to the effect that the accounts of a company, especially of a large engineering company like that, were simply a big machine to be handled by the head of the concern through the secretary and the cost clerks under him, with a view to the profitable management of the business. That experience had taught him a great deal about the question of costs; and he had been constantly in the habit of placing information in this way before the directors, by diagrams which could be read at a glance, as well as by the figures copied from the books which confirmed those diagrams, as no doubt had been done by many engineers in other concerns. Taking for instance the aggregate of the general costs, this formed one high curve, which was pitted against another high curve representing the output. The two curves together showed clearly at a glance that a certain output was required before any profit at all could be made; and anything beyond that output meant profit according to the amount of work. Similarly on an earlier occasion his own practice had independently been in the direction taken by the author. A railway, of which he had the

(Mr. David Joy.)

control many years ago, was equipped with excellent engines and rolling stock, but with such scanty appliances for repair, that he had to watch every wheel and almost every rivet of the engines so as to keep them all going, in order that the demands of the traffic department might be always fulfilled to the time. For this purpose he had constructed the simple form of diagram shown in Fig. 7, Plate 98, for enabling him to see constantly, not by figures which took a great deal of time to watch, but by a glance at a moment, what was the condition of the engines at any time, and not only of any single engine but also of the whole stock. The diagram in Fig. 7 was only a portion of a large sheet, which had been kept constantly posted up to date. The vertical columns represented successive weeks in the three months, June, July, and August. Each horizontal line represented an engine, the individual number of which was prefixed to the line. The full portions of the horizontal lines represented full running engines in perfect condition, and the dotted portions represented shaky engines which would do for shunting and perhaps for piloting. A gap in a line, following a dotted portion, as in line 6, denoted that a shaky engine had been sent into the shop, and after being repaired had been turned out perfect. Line 7 showed that a perfect engine had gone into the shop for a week or ten days, perhaps for turning tires, and on coming out again had been in perfect condition for full work. The whole sheet extended of course much further in both directions than the fragment here shown; and in this way it was easy to gather for any month or week how many engines there were in a perfect condition. This was the form in which he had had the information put together for his own use, and he had found it thoroughly handy.

Mr. E. J. Chambers considered that, although the use of such diagrams for many purposes in reference to profit making was not wholly new to engineers, yet unfortunately they were generally educated with too little knowledge of accountant's work, being too much interested in the engineering part of their business to devote a sufficient time to accounts. They were so much in the habit of expressing their ideas in graphic form that these diagrams appealed to them in a way in which they certainly would not appeal to an ordinary accountant. With the suggestion in page 505 to construct diagrams of departments he fully concurred, having himself made each of his departments a business in itself, as much independent of the other departments as if each had to buy from the general fund and sell to it, the general charges being distributed over the various departments. It would be a great advantage he was sure to have all these accounts shown by diagrams. But in order that the diagrams might be of real value, he considered the several costs should be classified somewhat as follows. First of all, whatever belonged entirely to manufacturing should be classed under the heading of "manufacturing": namely the labour and the material which were shown in the finished article. Second, as "manufacturing charges" should be classed things which did not appear in the finished casting or forging or other finished article, but were consumed in its production: such as fuel used, coke or limestone in a cupola, coke in a smith's fire, coal or gas in a heating furnace, and whatever else vanished in the process of manufacture. The third heading would be "establishment charges," that is, the dead charges of the works, such as the clerks' and foremen's wages, telegrams, postages, and various other charges connected with the establishment. About the foremen he was not quite sure; it was just possible that their wages should be classed under manufacturing charges in their several departments. The fourth class should be the "distributing charges," which being entirely outside the works, and having nothing whatever to do with the cost of manufacture, should be kept entirely separate. The cost of an article was its cost when loaded into the railway wagon or carrier's van or canal barge at the works; and anything beyond, or any circumstances in connection with the sale of the article at market price or with the rise or fall of the market, had nothing whatever to do with the cost of making the article. Fifth came the "outside charges": such as the expenses of travellers to secure orders, or of directors, or fees for advice. Diagrams such as those exhibited should be used to represent each of these five separate headings, and should be brought before the manager each month or oftener. They would enable him to take into his counsel the heads

(Mr. E. J. Chambers.)

of each one of his departments, making a point of consulting with them; because he would be at a great disadvantage if he had to effect all the saving and all the economies himself; if he merely gave orders for economies, he was not likely to see the full result of them, and therefore he should make a point of showing to the heads of the various departments the result of their respective labours. To a mechanic nothing would appeal better than a diagram showing the rise and fall of these various charges as each month went round. In this way he believed that, although not trained as accountants, engineers would be able to exercise their engineering skill to the best advantage. For though it might be a great thing for a man to be an able engineer, who could design machines that would work perfectly, yet, if he could not make the work pay, his ability would not be of a sterling quality.

Mr. Jameson fully agreed with the remarks of Mr. Chambers as to the importance of keeping separate the different kinds of charges, such as the manufacturing charges, the establishment charges, and the outside charges. In the preparation however of the diagrams illustrating the paper, in order to prevent having too many lines upon them, he had grouped these charges together and shown them all by a single line; smaller diagrams bearing these separate detail lines he should be happy to show to members desiring further information. Usually all the manufacturing charges were kept by themselves, detailed in the first instance and grouped at last; while such items as debenture interest went into establishment charges, which should also be detailed and grouped. A separate heading was also made for all petty-cash expenses, so that it could be seen exactly, at the close of each month or other period, whether the petty-cash expenditure was tolerably uniform, or whether it was rising or falling abnormally. Although in the paper he had principally urged the importance to the general manager of having before him the result of the work throughout the whole establishment, he fully appreciated also the importance and value of his being able to secure the intelligent co-operation of the heads of departments, by showing them in a simple form the detail results of their departmental work. As pointed out by Mr. Chambers, this was of great importance. Within his own knowledge a subordinate, having been shown from time to time diagrams of the results of his work, had started a system of diagrams for his own guidance, so as to keep constantly before himself any departure from the ideal result, and to be able to correct it as far as possible at once.

The paper was not meant to convey the idea that diagram accounts were in any respect a novelty of his own devising. They had been in extensive use for many years past in works of various kinds, and, where the diagrams were well designed, with the greatest advantage to those who had introduced them, as observed in one particular by Mr. Joy. What the paper was intended to make clear, as having come within his own experience, was the special advantage derivable from diagram accounts in engineering establishments, where fluctuations were so liable to occur in purchasing and selling prices, in wages, and especially in the amount of output; and where, too often, the results of these variations, in the relation of the percentage cost of labour and other matters, were to a large extent unobserved or misunderstood.

Mr. **Chambers** asked why debenture interest should be included in the cost of an article made in the works. Instead of appearing as part of the cost, ought it not really to be charged to the capital account? And if debenture interest were included, why not interest on capital?

Mr. **Jameson** was of opinion that, where debentures had been created, seeing that the interest thereon must under all circumstances be paid, it became in fact equivalent to such a charge as rent; and therefore in estimating the amount of profit or loss in the works it was necessary for a corresponding percentage to be added to the cost of whatever was done, in order to show the net result of the work. In a slack time, for instance, if too small a quantity of work was being done, the debenture interest might even be so great in proportion that it would really absorb the profit altogether. What engineers and manufacturers required to have

(Mr. Jameson.)

brought before them was the net result of the work which they were doing; and therefore he should himself include debenture interest with establishment charges as an item of cost. Interest on capital however he would omit, because that was a matter of profit. Foremen's wages he would not include in the establishment charges, but in the "manufacturing" of their respective departments.

The President had great pleasure in proposing a vote of thanks to Mr. Jameson for his interesting and useful paper.

MEMOIRS.

John Archbold was born at Haugh Head, Wooler, Northumberland, on 8th February 1838, whence while he was quite a child his parents removed to Cowpen Colliery, near Blyth. He served his apprenticeship as a colliery engineer at Bebside Colliery, near Newcastle-on-Tyne, and then went to Backworth Colliery. After this he held for a short time the position of engineer at Felling Colliery, near Gateshead, which he left to act as resident engineer to some patent fuel-works, commenced at Hendon, Sunderland. Afterwards he was appointed by the Stella Coal Co. engineer to their collieries near Blaydon-on-Tyne; and then went abroad for three years as engineer at a colliery in Labuan, Borneo. On returning to England he was appointed engineer at Tondu Colliery, South Wales; after which he was engineer at the Thorncliffe Collieries of Messrs. Newton, Chambers and Co. In February 1872 he was engaged by Messrs. Barber, Walker and Co., as engineer at their Eastwood Collieries, Notts., where he remained for the rest of his life. He devised a haulage clip of simple mechanism, which is doing good work at these collieries. For twelve years he was a member of the Greasley School Board, being vice-chairman for part of the time; he also took a great interest in the technical education movement in the parish. His death took place at his residence in Greasley on 3rd October 1897, after a long and painful illness, in his sixtieth year. He became a Member of this Institution in 1891.

John James Barrett was born on 17th September 1846 at Gharra in Scinde, India. From 1863 to 1867 he held the position of junior engineer on several steamers in the mercantile marine, including the British India Steam Navigation Co. During the Abyssinian expedition in 1867 he was appointed chief engineer, which position he held on various steamers. In 1872 he became chief engineer in the Turkish navy. In 1875 he was engaged as engineer for the Bombay Spinning and Weaving Mill, of which he was shortly afterwards appointed manager and superintendent engineer. In 1885 he started business as consulting and inspecting engineer in Bombay, where his death took place after a long and painful illness in August 1897, in his fifty-first year. He became a Member of this Institution in 1882.

The Rev. SAMUEL HAUGHTON was born in Carlow, Ireland, on 21st December 1821. Having been educated at the Carlow Diocesan School, he acquired under the Rev. John Emerson at Mayo a knowledge of Hebrew, botany, chemistry, astronomy, and the geology of the Leinster coalfield. Contemplating a clerical life, possibly abroad as a missionary, he attended clinically the county infirmary as a pupil of Dr. Thomas Rawson. He also took a keen interest in mechanics, and assisted his cousin and schoolfellow, Mr. S. Wilfred Haughton, to construct a model steam-engine, which worked to their satisfaction. At the age of seventeen he entered Trinity College, Dublin; and in 1843 at the age of twenty-two, he obtained besides his degree the first senior moderatorship in mathematics, gaining the gold medal. By the advice of his tutor, Dr. Salmon, now Provost of Trinity College, he competed for a fellowship, which he obtained in 1844, notwithstanding the time lost by an attack of fever and consequent prostration. The attainment of a fellowship within a year of the degree was unprecedented. He was ordained deacon in 1846, and priest in 1847, but never had pastoral charge. Retaining his fellowship, he devoted himself to the interests of the college, and in conjunction with his colleague, the Rev. Joseph Galbraith, established and conducted with conspicuous success a class for the preparation of students seeking commissions in the Royal Artillery and the Royal Engineers. In 1862 he obtained the degree of Doctor of Medicine of Dublin University, and was appointed successively registrar, and in 1879 chairman of the medical school, which he stimulated into bright and active life. He was also made a governor of Sir Patrick Dun's Hospital, which is closely connected with the University. He was joint author of the Galbraith and Haughton series of manuals. In 1851 he became professor of geology, and retained this post until 1881, when he was co-opted to the Board of Senior Fellows. He represented the University of Dublin on the General Medical Council from 1878 to 1896, and effectively advocated the claims of the Dublin schools of medicine. In 1873 he produced a book on Animal Mechanics, in which his early mechanical tastes are shown in combination with his surgical, physiological, and mathematical knowledge. He was president of the Royal Irish Academy from 1886 to 1891, and in addition to numerous mathematical papers printed in their transactions he published under their auspices a work on the tides of the Irish Seas, as the result of a long series of observations made by direction of the Academy and supervised by himself. For the Royal Zoological Society of Ireland, of which he was for many years the honorary secretary, he ultimately won a high and independent position. He became a fellow of the Royal Society in 1858, and received the degrees of D.C.L. of Oxford in 1868, LL.D. and M.D. of Cambridge in 1880, LL.D. of Edinburgh in 1884, and honorary M.D. of the University of Bologna in 1888; and was also honorary fellow of the Royal College of Surgeons, Ireland. In 1888 he was elected an Honorary Member of this Institution, on the occasion of the Summer Meeting being held for the second time in Trinity College, Dublin; and on behalf of Trinity College he had previously welcomed the Members on their first visit to Dublin in 1865. He was also a member of many other scientific societies both at home and abroad. Having suffered for some time from cardiac affection, he died on 31st October 1897, in his seventy-sixth year.

JOHN PITT KENNEDY, born at Dublin on 17th July 1824, was the son of Mr. William Kennedy of Lough Ash, County Tyrone, and nephew of Colonel John Pitt Kennedy, promoter and for many years consulting engineer of the Bombay Baroda and Central Indian Railway. Having served a pupilage under Sir John Macneill, he was appointed managing engineer of the Mallow Railway, and afterwards superintended the construction of the Londonderry and Coleraine

Railway. In 1853 he went to India, and spent three years on the construction of the Bombay and Baroda Railway. Returning to England in 1856, he proceeded to Turkey, and was appointed engineer for the Smyrna and Cassaba Railway. He succeeded his uncle as consulting engineer to the Bombay Baroda and Central Indian Railway, and afterwards held the post of secretary to that company for several years. His death took place in London from acute congestion of the lungs on 28th November 1897, at the age of seventy-three. He became a Member of this Institution in 1863, and was also a Member of the Institution of Civil Engineers.

James Platt was born in Manchester on 4th February 1834. In 1847 he entered the drawing office of Messrs. Francis Berry and Sons, Sowerby Bridge, for whom his father, Mr. John Platt, was manager. Having served his time in the shops, he was made foreman at the age of twenty. In 1859 he went to Gloucester to act as manager for Messrs. Savory and Son, for whom he designed some of their first agricultural engines, in which the winding drums encircled the boiler shell. In 1862 he started as a consulting engineer, and fitted out several mills in the Gloucester district with machinery of his own design; and also designed and superintended the erection of the first iron-cased blast-furnaces, which utilized the waste gases, in the Forest of Dean. In 1866 he joined Mr. Samuel Fielding in founding the firm of Fielding and Platt, Atlas Works, Gloucester. Having been asked by Mr. Ralph H. Tweddell in 1871 to undertake the sole manufacture of his hydraulic riveting machines, the firm made in 1873 the first hydraulic portable riveting machinery for the Primrose Street Railway Bridge of the Great Eastern Railway at Bishopsgate Street Station, London, which proved a great success. He was intimately associated with Mr. Tweddell in the development of the system of hydraulic machine-tools. In 1874, on the death of Mr. Fielding, who was succeeded by his two sons, he became senior partner. When visiting the United States in 1883 he read a paper on hydraulic machine-tools at the Franklin Institute, Philadelphia. In 1890 he made a second visit on the occasion of the Iron and Steel

Institute meeting. Whilst in Spain completing some wire tramway work during the Carlist rebellion he had several narrow escapes, and could only get away in a small steamer, which was under fire while running down the river, her funnel being riddled with bullets. On the conversion of the firm into a private company in 1895, he became chairman of the directors. After the death of Mr. Tweddell in 1895 the company took over all the rights connected with his hydraulic machinery. In municipal affairs he took a great interest, and became councillor, alderman, justice of the peace, and Mayor of Gloucester. He was deputy chairman of the Gloucester Wagon Co., a director of the gas works, a governor of the Gloucester Infirmary, a charity trustee, first president of the Gloucestershire Engineering Society, and a president of the Chamber of Commerce. While on a third visit to the United States in 1894 an internal complication began to develop itself, which ultimately caused his death at his residence in Gloucester on 29th December 1897, in his sixty-fourth year. He became a Member of this Institution in 1871, and was a regular attendant at the meetings, frequently taking part in the discussions; and he was a Member of Council from 1893. He was also a Member of the Institution of Civil Engineers, and of the Iron and Steel Institute.

Frederick Tasker was born in Sheffield on 27th September 1861. He served his time from 1875 to 1881 in the engineering works of Messrs. Tasker Sons and Co., Sheffield. In 1881 he became shop manager, and in 1884 was appointed manager of the works of the same firm. In 1893 he went for health to South Africa, where he resided until his death on 29th September 1897, at the age of thirty-six. He became a Member of this Institution in 1893.

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